EFFECTS OF VARIABLE-INTERVAL VALUE AND AMOUNT OF TRAINING ON STIMULUS GENERALIZATION

By

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Major Department: Psychology

Three experiments were conducted in which pigeons were trained to peck a key that was illuminated with a 501-nm light (Experiments I and III) or on which was projected a vertical line (Experiment II). Then generalization testing was conducted in extinction wherein different wavelengths of light or line orientations were projected on the key and responding had no programmed consequences. In Experiment I three groups of subjects were trained with a variable-interval 30-s, 120-s, or 240-s schedule of food presentation in the presence of a 501-nm light for ten 50-min sessions. Different wavelengths of light were presented during the generalization test. Absolute and relative generalization gradients were similar in shape for the three groups of subjects, a result that indicates that the shape of generalization gradients following single-stimulus training with a variable-interval schedule does not necessarily depend on the frequency of reinforcement in training. Experiment II was a systematic replication of Experiment I wherein pigeons were trained with either a variable-interval 30-s or 240-s schedule of food presentation in the presence of a vertical line for ten sessions. Different orientations of the line were presented during the generalization test. Again, gradients of generalization were similar for the two groups of subjects. In Experiment III subjects were trained to peck a key according to a variable-interval 240-s schedule of food presentation in the presence of a 501-nm light. These subjects experienced training until their response rates met a stability criterion (i.e., for 32, 40, 40, and 57 sessions each). Different wavelengths of light were presented during the generalization test. These data were compared with data from subjects in Experiment I who were trained with the same schedule. Absolute generalization gradients were displaced upward relative to subjects trained for only ten sessions, and relative generalization gradients were slightly flatter, although this effect was not very strong. These results indicate that prolonged training tended to result in more responding during the test and in slightly more generalization to stimuli not present during training.

Taken together the present results show that previously reported findings indicating that the extent of stimulus generalization is related to frequency of reinforcement are not easily replicated.

CHAPTER 1
INTRODUCTION

Purpose of the Present Study

The shape of a stimulus-generalization gradient depends on the procedure used to generate it and the training conditions in effect before the test for generalization occurs (Harrison, 1991; Mednick & Freedman, 1960; Rilling, 1977; Terrace, 1966). For example, Hearst, Koresko, and Poppen (1964) performed two experiments that showed that the extent of stimulus generalization during testing was a function of the schedule of reinforcement used to maintain responding during training. When pecking by pigeons was maintained in the presence of either a vertical or a horizontal line by a schedule of reinforcement in which key pecks were followed by food after some average amount of time, the extent of generalization to other line orientations was an inverse function of the frequency of reinforcement. That is, subjects that received less frequent reinforcement responded relatively more to line tilts that differed from the stimulus used during training than did subjects who received more frequent reinforcement. Because subjects experienced an equal number of training sessions of the same duration, however, the number of reinforcers earned during training also differed for the different groups. The original purpose of the present set of experiments was to answer two questions: 1) Will the relation between intermittency of reinforcer delivery and extent of stimulus generalization hold when wavelength of light, rather than line orientation, is the stimulus dimension? 2) Is the difference in extent of generalization for the different groups attributable to the difference in number of reinforcers earned during training?

Relevance of the Present Study

The results reported by Hearst, Koresko, and Poppen (1964) have important implications for applied psychology. One problem in applied behavior analysis and in other applications of psychology is the problem of generalization (Baer, Wolf, & Risley, 1968; Stokes & Baer, 1977). Adaptive skills that are taught in a therapeutic setting are intended to generalize to nontherapeutic settings but do not always do so. To the extent that generalization does not occur, therapy will be unsuccessful. Alternatively, a therapist might train a skill that is adaptive in one particular setting but inappropriate in another. This type of behavior, therefore, should be specific to one or a few particular situations and should not generalize extensively. For example, appropriate verbal behavior should generalize to most situations involving people. However, some interpersonal skills (e.g., those directed toward a significant other, perhaps) may be appropriate only in the presence of that individual and only in a particular setting. The data reported by Hearst et al. suggest that differing amounts of generalization can be programed by training responses using differing frequencies of reinforcement. It is important, therefore, to examine the robustness of the phenomenon reported by Hearst et al. because their results may provide a basis for the design of effective treatments.

If the phenomenon reported by Hearst, Koresko, and Poppen (1964) is robust, it is also important to analyze the effect more closely to determine the variables responsible for it. As mentioned above, a confound in their experiment makes the interpretation of results difficult. Different groups of subjects experienced different numbers of reinforcers during training. If the results of Hearst et al. are to be of use in designing behavioral technology, knowledge of the variables responsible is necessary. The relevance of the present research, then, lies in a) the examination of the robustness of the phenomenon reported by Hearst, Koresko, and Poppen (1964) and b) the analysis of the variables responsible for their results.

Stimulus Control

The study of stimulus generalization falls under the more general topic of stimulus control. Stimulus control refers to the extent to which a stimulus determines the probability of responding in its presence (Terrace, 1966). It occurs when a change in a stimulus results in a change in some characteristic (e.g., rate, probability) of responding (Rilling, 1977). The term stimulus control is a more general term than are the terms stimulus generalization and discrimination. "When an animal is trained in a stimulus control task, other stimuli, not present during training, may come to exert some degree of control of the animal's responding. This effect of the original training on control of responding by the new stimuli is referred to as generalization" (Harrison, 1991, p. 270). Discrimination, on the other hand, is said to occur when an animal responds differently in the presence of different stimuli. Animals can be trained to respond differently in the presence of different stimuli via a procedure called discrimination training. This procedure may be contrasted with single-stimulus training, wherein responses are reinforced in the presence of a particular stimulus. During discrimination training responding is differentially reinforced in the presence of (usually two) different stimuli. For example, responding may be reinforced in the presence of a stimulus (the positive stimulus, or S+), and not reinforced (i.e., extinguished) in the presence of another (the negative) stimulus (or S-) (Rilling, 1977). This procedure trains the animal to discriminate between (i.e., to respond differentially to) stimuli that differ with respect to some property.

During a test for stimulus control, which usually occurs after an organism has been trained to respond in the presence of a stimulus (or to respond differentially in the presence of each of two stimuli), a property of the stimulus is usually varied along some continuum (e.g., wavelength of light, frequency of a tone, angle of orientation of a line). This continuum is the stimulus dimension, or the dimension of generalization (Rilling, 1977). A gradient of stimulus control, or a gradient of stimulus generalization, is a function that relates the probability of responding to the value of the stimulus (Terrace, 1966). It is "obtained when the total number of responses to each of the stimulus values presented during the test are plotted against the dimension of generalization" (Rilling, 1977, p. 433).

The term stimulus control has some advantages over the terms generalization and discrimination. Stimulus control refers to the empirical relation between stimuli and responding. The terms, generalization and discrimination, also refer to empirical relations; however, these terms have traditionally been used to describe processes, rather than empirical functions (Terrace, 1966). According to Guttman (1963), the "inverse hypothesis" of stimulus generalization states that "generalization is the inverse of sensory discrimination, that a response will generalize to the extent that the organism does not discriminate stimulus differences" (p. 140). The statement that stimulus generalization is a function of psychophysical similarity between stimuli is a tautology, and the inverse hypothesis has not been supported by empirical data. The inverse hypothesis predicts that generalization gradients should match discrimination functions generated by psychophysical techniques. Guttman and Kalish (1956) compared generalization gradients of pigeons across the wavelength continuum, a stimulus dimension for which the discrimination function is known. Different groups of pigeons were trained to peck a key in the presence of different wavelengths of light. Then several wavelengths were presented in a test for generalization. Generalization gradients for all pigeons were very similar in form; they did not conform to the results expected if stimulus generalization were a function of psychophysical discriminability alone. This experiment showed that stimulus generalization is not solely a function of an animal's ability to discriminate stimuli and illustrated the problem with using terms that refer to processes to describe empirical relations. The use of such terms becomes a problem when they are regarded as explanations of the empirical relations to which they refer (Guttman, 1963; Terrace, 1966).

Rilling (1977) describes another problem with the use of the terms, generalization and discrimination, the fallacy of describing the same process with different words. Discrimination is defined as the failure to generalize; generalization is the failure to discriminate (Dinsmoor, 1995a; Rilling, 1977). According to Rilling, generalization and discrimination are best considered as opposite ends of a continuum of stimulus control.

Gradients of Stimulus Generalization

A stimulus-control, or stimulus-generalization, gradient shows the extent to which generalization occurs; that is, the extent to which stimuli not present during training control responding (or lack of responding in the presence of S-). According to Mednick and Freedman (1960), a gradient of stimulus generalization is observed when "the strength of these generalized responses (measured by frequency, latency, etc.) varies as an orderly function of the physical difference between the test stimuli and [the training stimulus]" (p. 170). A flat generalization gradient (slope=0) indicates no stimulus control along the dimension of generalization. That is, equivalent responding occurs regardless of the value of the stimulus property along that stimulus continuum. A nonzero slope, on the other hand, indicates control by the stimulus dimension.

The type of procedure used by Hearst et al. (1964) for studying stimulus generalization was devised by Skinner (1950) and refined by Guttman and Kalish (1956). A schedule of intermittent reinforcement is used to maintain responding in the presence of a stimulus (the training stimulus). Training consists of stimulus-on periods, during which the training stimulus is present and the schedule of reinforcement is in effect. These periods alternate with stimulus-off periods, during which the stimulus is not present, the chamber is dark, and responding has no programmed consequences. After some number of training sessions, a generalization test is conducted. The training stimulus and test stimuli are presented randomly during stimulus-on periods, and responding has no arranged consequences (i.e., extinction is in effect). The test stimuli differ from the training stimulus along some dimension (e.g., wavelength of light, frequency of a tone, angle of orientation of a line). Intermittent reinforcement is used during training to ensure high resistance to extinction in the generalization test (Guttman & Kalish, 1956; Skinner, 1950). A gradient of stimulus generalization can be constructed by plotting the number of responses in the presence of each stimulus as a function of the value of the stimulus along the dimension of generalization.

Several factors have been shown to affect the shape of generalization gradients generated by the procedure developed by Guttman and Kalish (1956) (Dinsmoor, 1995a; Harrison, 1991; Mednick & Freedman, 1960; Rilling, 1977; Terrace, 1966). Three of these factors are the focus of the present study: a) frequency, or schedule, of reinforcement used to maintain responding during training, b) dimension of generalization, and c) amount of training.

Frequency of Reinforcement

Hearst et al. (1964, Experiment II) used the procedure refined by Guttman and Kalish (1956) to investigate the relationship between frequency of reinforcement in training and the extent of generalization in testing. They trained five groups of pigeons to peck a key on which was projected a vertical or a horizontal line. Then key pecking was maintained by a variable-interval (VI) schedule, wherein a key peck was followed by 5-s access to grain on the average of every *t* s, where *t* was the parameter of the VI schedule. The groups differed with respect to this parameter; responding was maintained by a VI 30-s, a VI 60-s, a VI 120-s, a VI 180-s, or a VI 240-s schedule of food presentation in different groups of subjects. Ten to 11 sessions of training were conducted in which 30-s stimulus-on periods alternated with 10-s stimulus-off periods. The sessions were 50 min in duration and consisted of 75 stimulus-on/stimulus-off periods. The authors analyzed absolute and relative generalization and gradient slope.

Absolute generalization gradients plotted the total number of responses in the presence of each stimulus as a function of angular degrees from the line orientation used in training. For the measure of relative generalization, the peak of the gradient was defined as the stimulus to which the largest number of responses occurred (usually the training stimulus). The number of responses to each stimulus was divided by the number of responses to the peak stimulus. An index of absolute gradient slope originated by Hiss and Thomas (1963) was calculated according to the following formula:

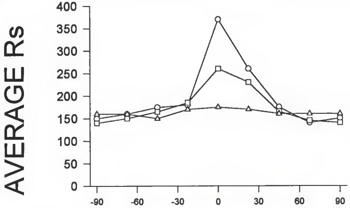
(total responses to the training stimulus/total responses to all stimuli) X 100.

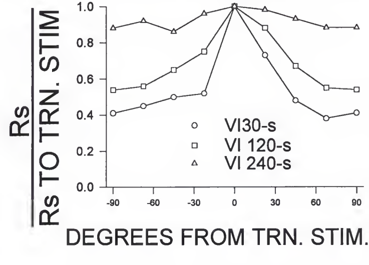
This number is the percentage of all responses emitted during the test that occurred in the presence of the training stimulus. Given eight test stimuli, the authors suggested that an index of gradient slope greater than 20% indicated that the gradient was steep. This would be true if the peak of the gradient occurred at the training stimulus; a value of 20% would indicate that proportionally more responses occurred in the presence of the training stimulus than in the presence of the other stimuli. An index of 12.5% would be obtained when the gradient was flat (although this value would not indicate a flat gradient if proportionally more responses occurred in the presence of a stimulus not present during training).

Hearst et al. (1964) found that relative generalization gradients were very steep for subjects trained with shorter VI schedules (VI 30-s, VI 60-s), that is, with more frequent reinforcement. Absolute generalization gradients showed higher peaks for these subjects, and there was an "inverse relationship between gradient slope and VI mean interval" (Hearst et al., 1964, p. 377). Gradients of absolute generalization for subjects trained with longer VI schedules were flat (VI 240-s) or almost flat (VI 180-s). In other words, the more intermittent the schedule of reinforcement in training, the flatter the generalization gradient (i.e., the more responding generalized to stimuli not present during training). On the other hand, higher reinforcement frequencies resulted in steeper gradients (i.e., less generalization to other stimuli).

Figure 1-1 shows absolute and relative generalization gradients replotted from the data presented by Hearst et al. (1964) from three groups of subjects,

Figure 1-1. Gradients of average absolute (upper panel) and relative (lower panel) generalization for three groups of pigeons trained with different VI schedules in the presence of either a vertical or a horizontal line. Absolute generalization (upper panel) refers to the total number of responses emitted in the presence of each test stimulus as a function of angular degrees from the training stimulus. Relative generalization (lower panel) refers to the number of responses emitted in the presence of each test stimulus expressed as a proportion of the number of responses to the peak stimulus (the stimulus to which the largest number of responses occurred). Circles represent data from subjects trained with a VI 30-s schedule, squares represent data from subjects trained with a VI 120-s schedule, and triangles represent data from subjects trained with a VI 240-s schedule. (Data replotted from Hearst, Koresko, & Poppen, 1964.)


ABSOLUTE GENERALIZATION


RELATIVE GENERALIZATION

those trained with a VI 30-s, VI 120-s, and VI 240-s schedule of reinforcement. Absolute and relative generalization gradients for subjects trained with the VI 30-s schedule are much steeper than those obtained from subjects trained with the VI 120-s and VI 240-s schedules. Absolute and relative generalization gradients for the VI 240-s group are flat, indicating no stimulus control by the line-orientation dimension, whereas gradients for the VI 120-s group have intermediate slopes. All groups responded about the same number of times to stimuli far from the training stimulus along the line-tilt continuum (e.g., 45-90 degrees from the training stimulus). An average of approximately 150 responses occurred in the presence of these stimuli that were presumed to be the most different from the training stimulus. This number is almost half the number of responses that occurred to the training stimulus itself for the VI 30-s group and approximately 60% of the number of responses in the presence of the training stimulus for the VI 120-s group.

Amount of Training

Hearst et al. (1964) suggested that the differences in shape of the generalization gradients could be due to a) the differential number of reinforcers obtained during training for the different groups or b) the different rates and patterns of responding that developed during training with different VI schedules. The original purpose of the present set of experiments was to examine the first explanation. In the study by Hearst et al. the number of training sessions prior to generalization testing was the same for all groups. Therefore, the amount of time spent in the presence of the training stimulus was held constant across groups;however, both the schedule of reinforcement and the total number of reinforcers obtained during training differed across the different groups. Subjects trained with shorter VI schedules earned more reinforcers during training than did subjects in the VI 120-s group, which earned more than did the VI 240-s subjects. Therefore, the variable responsible for the difference in results may not have been the schedule of reinforcement but rather the total number of reinforcers earned during training.

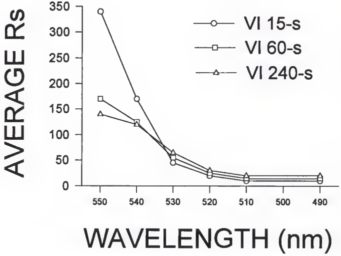
Dimension of Generalization

The present set of experiments was designed to examine the inverse relation between VI mean interval and steepness of slope of the generalization gradient using wavelength of light as the dimension of generalization. After replicating the procedure used by Hearst et al. (1964) with wavelength of light as the dimension of generalization, the procedure was to be repeated, with the number of reinforcers earned during training held constant across the different groups. This was to be accomplished by conducting more sessions with the subjects that were trained with the longer VI schedules during training. In this way, the number of reinforcers earned during training would be similar; however, the time spent in the presence of the training stimulus would differ across the different groups.

Wavelength of light was chosen as the stimulus dimension in the present Experiment I because Haber and Kalish (1963) had compared gradients of generalization across the wavelength dimension and obtained results that differed from those of Hearst et al. (1964). In the study by Haber and Kalish pigeons were trained to peck a key in the presence of a 550-nm light. Then pecking was reinforced according to a VI 15-s, a VI 60-s, or a VI 240-s schedule of reinforcement. Generalization testing was conducted in extinction with different wavelengths of light as the test stimuli. The results from this experiment have been replotted in Figure 1-2, which shows the average number of responses emitted in the presence of each stimulus during the generalization test for the different groups of subjects.

The gradient for the VI 15-s subjects is steeper than the gradients for the other groups, which look very similar. A comparison of Figures 1-1 and 1-2 shows that the gradients obtained for the VI 240-s subjects in the two studies are remarkably dissimilar. Whereas the gradients obtained for subjects trained with a VI 240-s schedule using line orientation as the stimulus dimension are almost completely flat (Figure 1-1), the absolute generalization gradient for the VI 240-s subjects tested with wavelength of light as the stimulus dimension is relatively steep (Figure 1-2). This result suggests that the relation between VI mean interval and extent of generalization reported by Hearst et al. (1964) is not as dramatic when wavelength of light is the stimulus dimension. The gradient for the VI 240-s subjects is not flat in the study by Haber and Kalish (1963); nor is it

Figure 1-2. Gradients of average absolute generalization for three groups of pigeons trained with different VI schedules, VI 15-s (circles), VI 60-s (squares), or VI 240-s (triangles) in the presence of a 550-nm light. Absolute generalization refers to the total number of responses emitted in the presence of each test stimulus as a function of wavelength of the stimulus. (Data replotted from Haber & Kalish, 1963.)



ABSOLUTE GENERALIZATION

noticeably different from the gradient obtained for the VI 60-s group. Another dramatic difference in the results of the two experiments is the large number of responses emitted in the presence of line orientations that were far from the training stimulus on the dimension of generalization (Hearst et al., 1964; see Figure 1-1) relative to the few responses emitted in the presence of wavelengths that differed most from the training stimulus (Haber & Kalish, 1963; see Figure 1-2). Subjects trained to respond in the presence of a particular wavelength of light generalized less to stimuli far from the training stimulus along the stimulus continuum than did subjects trained to respond to a line orientation and tested with different line tilts.

Besides the dimension of generalization, there were other differences between the procedure used in the experiment conducted by Haber and Kalish (1963) and that used by Hearst et al. (1964). In the former study, training consisted of 60-s stimulus-on periods, whereas testing consisted of 30-s stimulus-on periods. In the Hearst et al. study all stimulus-on periods were 30 s. Subjects in the experiment by Haber and Kalish experienced the same number of training sessions as subjects in the study by Hearst et al. (ten); however, sessions were 30 min long in the former and 50 min in the latter study. Subjects were maintained at 80% (Haber & Kalish) or 75% (Hearst et al.) of their free-feeding weights. Haber and Kalish did not mention whether their test sessions began with a "warm-up" period, during which training conditions were in effect. Although these differences seem minor and unlikely to produce such a discrepancy in results of the two procedures, the present Experiment I was designed to replicate the procedures used by Hearst et al. as closely as possible in an attempt to extend the generality of their findings to the wavelength dimension. Besides the dimension of generalization, the only procedural differences between the present Experiment I and the experiment by Hearst et al. are as follows: 1) Reinforcers consisted of 4-s, not 5-s, access to grain. 2) Nine, not eight, stimuli were presented during the generalization test. 3) The training stimulus had a value located at one end of the stimulus continuum, as in the study by Haber and Kalish, rather than a value at the midpoint of the continuum, as in the study by Hearst et al.

CHAPTER 2
EXPERIMENT I

Introduction

The purpose of Experiment I was to see if the relation found by Hearst et al. (1964) between frequency of reinforcement and extent of generalization would hold when wavelength, rather than line tilt, was the stimulus dimension. The procedures used by Hearst et al. were replicated as closely as possible except that the stimuli used in training and testing were different wavelengths of light, rather than different orientations of a line. Three groups were studied: during training responding was maintained by a VI 30-s, a VI 120-s, or a VI 240-s schedule of reinforcement.

Hearst et al. (1964) attributed their results to the differential control of responding by exteroceptive vs. interoceptive or proprioceptive cues. In their Experiment I the authors compared generalization gradients for subjects trained with a VI 60-s schedule with those obtained from subjects trained with a differential-reinforcement-of-low-rate (DRL) schedule. In a DRL schedule a reinforcer is delivered following two pecks that are separated by some minimal amount of time (an interresponse time, or IRT). According to the authors, "DRL behavior is relatively more dependent than VI on internal, nonexteroceptive stimuli, since these kinds of stimuli are presumably involved in mediating the temporal discriminations and collateral behavior characteristic of DRL" (p. 370; but see Gray, 1976). If this statement is true, one would expect that generalization gradients along some exteroceptive stimulus continuum would be flatter for these subjects than for subjects responding according to a VI schedule in which control by exteroceptive stimuli is, presumably, more prominent. Indeed, generalization gradients for the DRL subjects in the Hearst et al. study were flat, whereas gradients for the subjects trained with the VI 60-s schedule were relatively steep.

The authors applied this rationale to the results from their Experiment II in which generalization gradients were flat for the VI 240-s subjects and steep for the VI 30-s subjects. According to this account, contingencies that produce low rates of responding are more likely to produce "stereotyped 'mediating' response chains" (Hearst et al., 1964, p. 378) and, therefore, flatter generalization gradients along exteroceptive stimulus dimensions than contingencies that produce high response rates. Because less frequent reinforcement (i.e., longer VI mean intervals) usually results in lower response rates than more frequent reinforcement (e.g., VI 30-s), control of responding by exteroceptive cues is stronger for subjects trained with short VI mean intervals than for subjects trained with long VI mean intervals. Hearst et al. (1964) state, however, that response "rate per se is apparently not the critical factor but, rather, the pattern of responding and the relative amount and kind of mediating behavior that emerges" (p. 379).

Thomas and Switalski (1966) examined this hypothesis by comparing gradients of generalization for subjects trained with variable-ratio (VR) schedules with gradients for subjects trained with VI schedules in which reinforcer availability was yoked to reinforcer availability in the VR sessions. In a VR schedule reinforcers are delivered following an average number of responses. In this type of schedule the reinforcement rate is a direct function of the response rate, and high response rates are usually generated. By yoking reinforcer availability for a VI subject to the delivery of reinforcement for a VR subject, a VI schedule can be arranged wherein one response results in reinforcer delivery at approximately the same intervals as reinforcers are delivered for the VR subject. In this procedure, reinforcement rate is held approximately constant, whereas the schedule of reinforcement (VR vs. VI) and the number of responses per reinforcer are not. Using this procedure Thomas and Switalski (1966) found that generalization gradients for the VR subjects were slightly flatter than gradients for the VI subjects. The authors interpreted these results as evidence that proprioceptive feedback from fast responding during the VR schedule was a cue for further responding. The addition of this proprioceptive cue attenuated stimulus control by other, exteroceptive, cues. The authors cite further evidence for this hypothesis, including the fact that when responding decreased during the generalization test, the gradients became steeper.

There are difficulties presented by the interpretation suggested by Hearst et al. (1964) and advocated by Thomas and Switalski (1966). Hearst et al. claimed that training with DRL and VI schedules with longer mean intervals results in flatter generalization gradients because DRL and VI schedules generate lower response rates and stimulus control of responding by interoceptive or proprioceptive cues. Thomas and Switalski argued that training with VR schedules results in flatter gradients because VR schedules generate high response rates and stimulus control of responding by proprioceptive cues. Hearst et al. found no correlation between response rate and extent of generalization; nor did Thomas and King (1959).

Another problem with this analysis is that steep generalization gradients can be obtained following training with procedures that should produce flat gradients if this interpretation is accurate. Yarczower, Gollub, and Dickson (1969), for example, obtained relatively steep gradients along the wavelength dimension using a contingency that involved a DRL schedule. In their experiment key pecking by different groups of pigeons was maintained by simple or multiple schedules in which different response rates were generated by the use of a DRL contingency in tandem with VI schedules, and reinforcement rates could be held constant. The authors concluded that "a contingency which contains a minimal interresponse time does not necessarily weaken stimulus control by an exteroceptive stimulus" (Yarczower et al., 1969, p. 631).

Few researchers (Haber & Kalish, 1963; Terrace, 1964, as cited in Terrace, 1966) have examined the relation reported by Hearst et al. (1964, Experiment II) between frequency of reinforcement during single-stimulus training and extent of generalization in testing. Eckerman (1969), however, conducted discrimination training in which the probability of reinforcement in the presence of the positive stimulus (S+) varied across groups while the probability of reinforcement in the presence of the negative stimulus (S-) was always zero. Stimulus control was said to exist if there was a reliable difference in response rates in the presence of the two stimuli. The procedure consisted of a successive discrimination wherein following a peck on Key A, Key B was illuminated with one of two stimuli, either S+ or S- (red or green lights). When Key B was illuminated with the color designated S+, there was some probability that reinforcement would be delivered for the first peck after 12 s. In this case, the keylight remained on until the delivery of the reinforcer. A 12-s intertrial interval (ITI) followed. The probability of reinforcement following the first peck after 12 s was 1.00, 0.60, 0.30, or 0.16 for different groups of pigeons. When Key B was illuminated with the color designated S-, the keylight remained on for 12 s but no reinforcer was delivered. A 15-s ITI followed. Before this discrimination-training procedure single-stimulus training was conducted wherein Key B was illuminated with a white keylight, and the probability of reinforcer delivery for the first peck after 12 s was 1.00. Therefore, the response was established when discrimination training began, and the development of stimulus control could be assessed by measuring the relative rates of responding in the presence of S+ and S-.

Response rates during S+ remained constant while rates during S- decreased over the course of discrimination training. The ratio of responses emitted in the presence of S- relative to the number of responses emitted in the presence of S+ generally was higher following training with a lower probability of reinforcement in the presence of S+. That is, subjects that experienced a lower probability, or frequency, of reinforcement responded relatively more in the presence of S- and therefore showed less stimulus control by this measure than did subjects who experienced higher probabilities of reinforcement. Also, the number of S- presentations in which responding occurred was greater for subjects experiencing lower probabilities of reinforcement than for subjects experiencing higher probabilities of reinforcement. The final level of stimulus control attained, however, was similar for all groups and occurred after similar numbers of reinforcer deliveries. These results suggest that the extent of stimulus control attainable does not depend on the frequency of reinforcement used in training; however, the total number of reinforcers delivered may be an important determinant of the extent of stimulus control. If this hypothesis is true (and it was examined in Experiment III), it may be that generalization gradients for the VI 240-s subjects in the study by Hearst et al. (1964) were flatter because the number of reinforcers obtained during training was insufficient to establish the extent of stimulus control established with subjects trained with shorter VI values and therefore more reinforcers.

The purpose of the present Experiment I was to replicate the procedure used by Hearst et al. (1964) using wavelength of light, rather than line tilt, as the stimulus dimension. If the relation reported by Hearst et al. between frequency of reinforcement in training and extent of generalization in testing was found, the experiment was to be replicated with the number of reinforcers obtained during training held constant across groups.

Method

Subjects

Twelve adult, experimentally naive White Carneau pigeons of indeterminate sex were maintained at 75% of their free-feeding weights via supplemental feeding of mixed grain after experimental sessions. The pigeons were housed in individual stainless steel cages in a temperature-controlled colony room under a 16:8-hr light/dark cycle. They had continuous access to water and health grit in their home cages.

Apparatus

Sessions were conducted in a standard operant-conditioning chamber for pigeons (Lehigh Valley Electronics, Model 1519C). The work area was 31 cm wide, 37 cm tall, and 35 cm deep. The walls were white, and the work panel was gray aluminum. A response key, 2.5 cm in diameter, was centered on the work panel 25 cm above the floor. The key required a force of approximately 0.19 N (19 g) to count as a response and produce a 50-ms feedback tone. A projector (Industrial Electronic Engineers, Inc., Model 10-OW78-1820-L) was situated behind the response key and included 1.1-W, 28-Vdc lamps that could project the stimuli in front of them onto the key. These stimuli included ten Kodak Wratten filters, two each of filter numbers 65, 74, 99, 73, and 72B. "When illuminated by a standard tungsten illuminant (illuminant A, with a color temperature of 2848K) these filters have dominant wavelengths of 501, 538, 555, 576, and 606 nm, respectively" (Lyons & Klipec, 1971, p. 232). For each stimulus presentation two lamps were lit (Sylvania miniature lamps, number 1820, with a color temperature of approximately 2800 to 3000K). The illumination of nine different pairs of filters resulted in the projection of nine different dominant wavelengths of light on the key (501, 517, 538, 549, 555, 559, 576, 587, and 606 nm), based on illuminant A. ("The use of another tungsten light source would produce somewhat different values;" Lyons & Klipec, 1971, p. 232). Each filter has different luminance transmittance characteristics; therefore, brightness was not equated across the different stimuli.

A 1.1-W, 28-Vdc lamp located behind an aluminum shield served as a houselight. It was located above the response key 2.5 cm from the ceiling of the chamber. Reinforcement was 4-s access to mixed grain, which was delivered through a 6- X 5-cm aperture below the response key and 10 cm above the floor. The feeder was illuminated by a 1.1-W, 28-Vdc lamp during reinforcement, at which time the houselight and keylight were off. White masking noise was present in the room where the chamber was located, and a ventilation fan mounted in the back wall of the chamber provided additional masking noise. There was an observation window in the door of the chamber. The window was completely covered, except for a small hole through which the pigeon could be observed.

A custom-built computer that operated under the ECBasic control system (Walter & Palya, 1984) and that was interfaced with an IBM-compatible computer located in an adjacent room programmed contingencies and collected data. A Gerbrands Model C-3 cumulative response recorder provided continuous recording of responses.

Procedure

Preliminary training. Sessions were conducted daily at about the same time each day. Preliminary training consisted of adaptation, magazine training, and key peck shaping. Pigeons were placed in the chamber with only the houselight on for one to three 20- to 30-min sessions (adaptation). Then magazine training began. Initially, the pigeons were placed in the chamber with the feeder raised and the feeder light on. When the pigeons ate continuously from the feeder for about 10 s, the feeder was raised and lowered quickly to habituate the pigeons to the sound of the magazine. Then the time between feeder operations was increased gradually. The houselight was on and the feeder light was off between feeder operations. Magazine training continued until the pigeon went immediately to the feeder and began eating from it whenever it was raised. This phase lasted between one and five sessions, each of which ended after approximately 30 min or until about 40 food presentations occurred.

Key peck shaping was accomplished via the method of differential reinforcement of successive approximations. The keylight was illuminated from behind and the 501-nm light (the training stimulus) was projected onto it.

Initially, movements toward the key were followed by food delivery. Then successive approximations toward a key peck were reinforced. Once a key peck had been emitted, a fixed-ratio (FR) 1 schedule of food presentation was in effect, wherein every key peck resulted in the delivery of mixed grain. Key peck shaping lasted for one to five sessions. Shaping sessions lasted for about 30 min or until 40 to 50 reinforcers were delivered. The FR 1 schedule was in effect until pigeons received a total of 95 to 140 reinforcements (40 to 50 reinforcements per session).

Variable-interval training. Training with variable-interval (VI) schedules of reinforcement followed the FR 1 condition. The twelve pigeons were assigned randomly to three groups of four subjects each. The groups differed according to the schedule of reinforcement in effect during training: key pecks were reinforced according to a VI 30-s, VI 120-s, or VI 240-s schedule of food presentation.

Sessions began with a 3-min blackout (all lights in the chamber off and no consequences for responding). Then 30-s stimulus-on periods alternated with 10-s stimulus-off periods. During stimulus-on periods the houselight was on and the keylight was illuminated with the 501-nm wavelength of light (the training stimulus), and the schedule of reinforcment was in effect. For the three groups the first peck after an average of 30 s, 120 s, or 240 s turned off the houselight, turned on the feeder light, and operated the feeder for 4 s. During stimulus-off periods blackout conditions were in effect (i.e., all lights in the chamber off and no consequences for responding), and the timer for the VI schedule was halted. The timer resumed where it left off when stimulus-on conditions were again in effect. Sessions lasted for 50 min of schedule time (not including the time that the feeder was raised) and included 75 stimulus-on/stimulus-off periods. Variable-interval training conditions were in effect for ten sessions. To ensure that responding did not extinguish during the transition from FR 1 to VI 120-s and VI 240-s, the first interval of the first session of VI training for these two groups was the shortest interval in the list of interval values. For the remaining sessions, interval values were selected randomly, as described below.

Intervals for the VI schedules came from a list of values determined by Catania and Reynolds' (1968) equation for generating constant-probability VI schedules. An average ofo 75 intervals per session for the VI 30-s schedule (37.5 min of schedule time and one reinforcer delivery on the average of every 30 s) came from eight sequences of ten values that ranged from 3.0 to 87.9 s. Interval values were selected randomly without replacement every ten stimulus presentations from the list of ten values. When these values were exhausted, the list was repeated and interval values were again selected randomly without replacement. This process was repeated every ten stimulus presentations until the session was completed. An average of 19 intervals per session for the VI 120-s schedule (37.5 min of schedule time and one reinforcer delivery on the average of every 2 min) came from a list of ten values that ranged from 12.0 to 351.4 s. Interval values were selected in the same way as for the VI 30-s schedule. Nine intervals per session, on average, for the VI 240-s schedule (37.5 min of schedule time and one reinforcer delivery on the average of every 4 min) were selected randomly without replacement from a list of ten values that ranged from 24.0 to 702.9 s.

The data collected included responses during stimulus-on and stimulus-off periods, latencies to respond during stimulus-on periods, and reinforcer deliveries. Response rate, reinforcer rate, and mean latency were calculated.

Generalization testing. Following a 3-min blackout, training conditions were in effect for 10 min (including 7.5 min of schedule time and 2.5 min of stimulus-off time). Then generalization testing began, and responding during the test had no programmed consequences (i.e., extinction was in effect). An average of 15 intervals for the VI 30-s schedule were selected randomly without replacement from the list of ten intervals used in training. Again, when the list of ten intervals was exhausted the intervals were selected randomly without replacement from the same ten intervals. Four intervals, on average, for the VI 120-s schedule were randomly selected without replacement from the list of ten intervals used in training. Two intervals, on average, for the VI 240-s schedule were randomly selected without replacement from the list of ten intervals used in training. The data collected during the training phase were also collected during this period.

Following this preliminary period testing began. Thirty-second stimulus-on periods continued to alternate with 10-s stimulus-off periods. Ten blocks occurred in a single session, and each block consisted of nine stimulus presentations, one of each of nine stimuli. The order of stimulus presentation was determined randomly, with the stipulation that each stimulus was presented once per block.

This process was repeated nine times, for a total of ten blocks, or 90 stimulus presentation, (not including the preliminary training period).

Data were collected separately for each stimulus-on period. The wavelength presented, number of responses, and latency were recorded for each stimulus-on period, and the total number of responses during stimulus-off periods was recorded for each block. Response rate for each stimulus-on period was calculated.

Results and Discussion

Training

Key pecking by all but one subject (8353 from the VI 240-s group) was well maintained following the transition from the FR 1 to the VI schedule. For these subjects response rates increased across sessions, and the obtained rate of reinforcement approximately equalled the programmed reinforcement rate during all sessions of training. Subject 8353 pecked at a very low rate on the first day of VI training (approximately 2 responses per min), and the reinforcement rate for this session was 0.13 reinforcers per min. This subject responded very little or not at all during the next seven sessions, and reinforcement rate varied from 0 to 0.05 reinforcers per min. During the remaining two sessions of training, response rates increased, and reinforcement rate was 0.25 reinforcers per min, the programmed rate of reinforcement. Another subject in the VI 240-s group (3530) responded at a lower rate than did any of the other subjects (about 5 responses per min) except

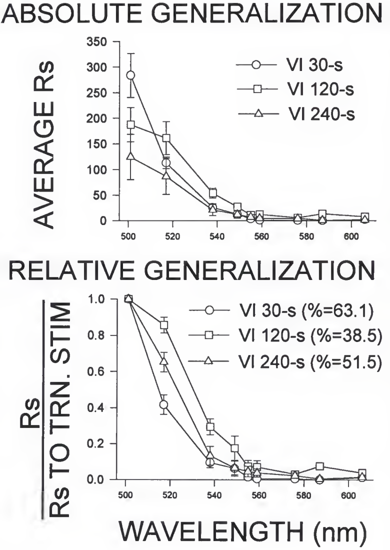
Subject 8353 at the beginning of training, and its rate of reinforcement varied from 0.16 to 0.24 reinforcers per min.

Response rates during the last session of training were highest for the VI 30-s subjects (mean=50.2 responses per min). Average response rates for the VI 120-s and VI 240-s groups were 31.9 and 18.0 responses per min, respectively. Response rates during the short training period that preceded the generalization test were similar to response rates during the last session of training. Average rates were 55.6, 33.8, and 25.7 responses per min for the VI 30-s, VI 120-s, and VI 240-s subjects, respectively.

Absolute and Relative Generalization and Index of Gradient Slope

Figure 2-1 shows gradients of average absolute (upper panel) and relative (lower panel) generalization for the VI 30-s, VI 120-s, and VI 240-s groups. The upper graph shows the average number of responses emitted in the presence of each test stimulus as a function of wavelength of the stimulus. Subjects trained with the VI 30-s schedule emitted slighty more responses to the stimulus used in training than did subjects in the other two groups, which emitted a similar number of responses to this stimulus. (Note that bars around points, which represent standard errors, overlap for these two groups.) The gradient for the VI 30-s group appears slightly steeper than the gradients for the VI 120-s and VI 240-s groups. However, a two-factor, repeated-measures ANOVA with VI mean interval as the between-subjects factor and stimulus value as the within-subjects factor indicates that the main effect of VI mean interval on responding was not

Figure 2-1. Gradients of average absolute (upper panel) and relative (lower panel) generalization for subjects trained with a VI 30-s (circles), a VI 120-s (squares), or a VI 240-s (triangles) schedule of reinforcement in the presence of a 501-nm light. Absolute generalization (upper panel) refers to the total number of responses emitted in the presence of each test stimulus as a function of wavelength of the stimulus in nm. Relative generalization (lower panel) refers to the total number of responses emitted in the presence of each test stimulus expressed as a proportion of the number of responses to the training stimulus. Bars around control points represent standard error. Also shown are average indexes of gradient slope (numbers in parentheses), or the percentage of total test responses that were emitted in the presence of the training stimulus.



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statistically significant ($F=2.145$, $p>.05$, $df=2$). There was a significant main effect of wavelength ($F=59.623$, $p<.05$, $df=8$) and a statistically significant interaction effect ($F=3.58$, $p<.05$, $df=16$). These results show that the VI schedule used in training hada statistically significant effect on the extent of generalization that depended on the wavelength of the stimulus.

Despite the statistically significant interaction effect, a comparison of the upper panels of Figures 1-1 and 2-1 shows that absolute generalization gradients generated by subjects in the VI 120-s and VI 240-s groups in the present study are much steeper than the gradients obtained by Hearst et al. (1964) for subjects trained with the same VI mean intervals. Whereas the gradient for the VI 240-s subjects is flat in the Hearst et al. study, the gradient obtained for the VI 240-s group in the present study is relatively steep. Another obvious difference in results of the two experiments is in the number of responses emitted in the presence of stimuli presumed to be the most different from the training stimulus, that is, the stimuli at the ends of the continua. Whereas approximately 150 responses were emitted to stimuli at the ends of the line-tilt continuum in the Hearst et al. study, almost none (0-17 total responses) were emitted to stimuli at the end of the wavelength continuum in the present study. It may be argued that this comparison is not a fair one given that in the present procedure subjects were trained with stimuli whose values were located on only one side of the wavelength continuum relative to the value of the training stimulus, whereas Hearst et al. tested their subjects with stimuli whose values were located on either side of the line-tilt continuum relative to the location of the value of the training stimulus. In the present study, therefore, the most extreme test stimulus was the most distant of eight stimuli, whereas in the Hearst et al. study the most different test stimulus was separated from the training stimulus by only three intervening test stimuli. However, if one considers only the data for the training stimulus and the four stimuli closest to the training stimulus in the present study, the above description still holds. That is, very few responses occurred to a test stimulus only three stimuli removed from the training stimulus. Of course, wavelength and line orientation are different stimulus dimensions and may be scaled very differently.

For the measures of relative generalization, the peak of the gradient was set at the training stimulus. Response totals for the other stimuli were expressed as proportions of this value, with the peak therefore set equal to 1.0. In the present study the peak of the gradient always occurred at the training stimulus for all subjects. In the Hearst et al. (1964) study, the peak did not always occur at the training stimulus for individual subjects, and the peak was defined as the stimulus to which the largest number of responses occurred. It makes sense, however, to characterize relative generalization as a proportion of the number of responses to the training stimulus, not as a proportion of the peak value, which may or may not occur at the training stimulus. Relative generalization is characterized in this way in the remainder of this paper.

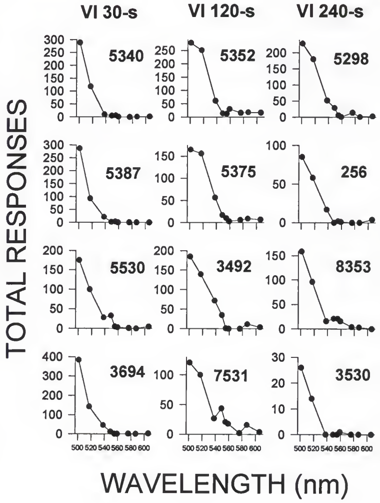
Figure 2-1 (lower panel) shows that the gradients of average relative generalization were very similar for the three groups of subjects. A two-factor, repeated-measures ANOVA of the effects of the between-subjects factor, VI mean interval, and the within-subjects factor, wavelength, indicates that the differences among groups are statistically significant (F=15.24, p<.05, df=2). The effect of stimulus value was also statistically significant (F=144.75, p<.05, df=7), as was the interaction effect (F=5.476, p<.05, df=14). The statistically significant interaction effect results from the fact that there are differences in the extent of generalization to stimuli close to the training stimulus along the wavelength dimension but not in the extent of generalization to more distant stimuli. The main difference in amount of relative generalization between the groups is in the relative generalization to the stimulus presumed to be most similar to the training stimulus, 517 nm. Relative generalization to 517 nm was slightly greater for the VI 120-s group, and error bars do not overlap with the other groups of subjects at the 517- and 538-nm stimuli. However, relative generalization to the other test stimuli is similar for all groups. The means are very similar and range bars overlap for the three groups (except at the 586-nm stimulus for the VI 120-s group).

A comparison of the lower panels of Figures 1-1 and 2-1 shows that relative generalization gradients obtained in the present study were steeper than those obtained by Hearst et al. (1964), especially for subjects trained with a 240-s VI mean interval. The relative generalization gradient for VI 240-s subjects obtained by Hearst et al. is flat; the gradient for VI 240-s subjects in the present study is steep. The lower panel of Figure 2-1 also shows the average index of gradient slope (values in parentheses) for the three groups. Because there were nine stimuli in the generalization test, a value of this index of 11.1% would correspond with a relatively flat gradient (i.e., one ninth of the responses to the nine test stimuli occurred in the presence of the training stimulus) if the proportion of responses to other stimuli did not exceed this number by very much. By this measure, the gradients for the VI 30-s and VI 240-s subjects are steeper than the gradient for the VI 120-s subjects. That is, for these subjects, on average, 63.1% and 51.5%, respectively, of responses during the test occurred in the presence of the training stimulus, whereas an average of 38.5% of total responses occurred in the presence of the training stimulus for the VI 120-s group. Indexes of gradient slope ranged from 50.0 to 70.7% for the VI 30-s subjects, from 34.3 to 41.3% for the VI 120-s subjects, and from 44.5 to 63.4% for the VI 240-s subjects. The ranges therefore overlap for the VI 30-s and VI 240-s groups, and the highest value of the index of gradient slope in the VI 120-s group was slightly less than the lowest index in the VI 240-s group.

Hearst et al. (1964) did not report the values they obtained for the measure of index of gradient slope for their VI 30-s, VI 120-s, or VI 240-s subjects but did report that the differences among all five groups (including VI 60-s and VI 180-s groups) were statistically significant. They did report indexes of gradient slope for 20 subjects trained with a VI 60-s schedule. The average index of gradient slope was 27.5%, and individual values ranged from 13.2% to 56.2%. Nineteen of these values were below the range of indexes of gradient slope for subjects trained with the VI 30-s and VI 240-s schedules in the present study, and 16 were below the range of indexes for subjects in the VI 120-s group of the present study. If this index is a valid measure of steepness of gradient slope (and it seems to be in the present study; that is, larger numbers correspond with steeper slopes, and smaller numbers correspond with flatter individual gradients), the relation reported by Hearst et al. predicts that average index of gradient slope for their VI 60-s subjects should be between the average index of gradient slope for subjects trained with the VI 30-s and VI 120-s schedules in the present study. This is not the case, however; indeed, gradient slopes are steeper for the VI 240-s subjects in the present study than for subjects trained with the VI 60-s schedule in the study by Hearst et al.

The shapes of the gradients of average absolute and relative generalization are representative of the gradients for individual subjects, as are the average indexes of gradient slope. Individual-subject data for absolute generalization are presented in Figure 2-2. The left panels show data for the VI 30-s group, the center panels show data for the VI 120-s group, and the right panels are generalization gradients for subjects trained with the VI 240-s schedule of reinforcement. Subjects in the VI 30-s and VI 120-s groups emitted a similar average number of responses during the generalization test, whereas subjects in the VI 240-s group emitted a smaller average number of responses in the test. The range of response totals for the VI 240-s group overlapped with the ranges

Figure 2-2. Gradients of absolute generalization for individual subjects trained with a VI 30-s (left panels), a VI 120-s (center panels), or a VI 240-s (right panels) schedule of reinforcement in the presence of a 501-nm light. See Figure 2-1 for definition of absolute generalization.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for the other two groups, indicating that this difference was not reliable across subjects in the same group. The average number of responses emitted during the generalization test was 445 for the VI 30-s group, and response totals ranged from 350 to 594 responses. For the VI 120-s subjects, the average number of responsesemitted in the test was 483, and total responses ranged from 353 to 699 responses. The VI 240-s group emitted an average of 265 responses during generalization testing, and their response totals ranged from 41 to 515 responses. These results are consistent with those reported by Hearst et al. (1964), who observed that the total number of responses emitted during the generalization test did not differ significantly across groups.

Absolute (Figure 2-2) and relative (data not shown) generalization gradients for individual subjects are relatively steep, and visual inspection of these graphs does not show any obvious differences in gradient shape between groups. One slight difference is in the number of responses (Figure 2-2) in the presence of the stimulus closest to the training stimulus on the wavelength continuum (517 nm). Subjects in the VI 120-s group generally responded more to this stimulus than did subjects in the other two groups. There are exceptions, however; relative generalization to this stimulus for Subject 3492 (0.75), a VI 120-s subject, was less than that for Subject 5298 (0.79), a VI 240-s subject. The subjects in the VI 30-s group appeared to generalize least to this stimulus. However, this statement is an overgeneralization, too. Relative generalization to the 517-nm light was 0.57 for Subject 5530, a VI 30-s subject, and 0.54 and 0.60, respectively, for Subjects 3530 and 8353, two subjects in the VI 240-s group. Overall, then, the shapes of the generalization gradients are remarkably similar across individual subjects, regardless of their training history.

In the present study the peaks of all gradients are located above the value of the training stimulus along the wavelength continuum, and all gradients show orderly decrements in responding as a function of distance from the training stimulus. Subjects responded very little to stimuli distant from the training stimulus along the wavelength continuum. In the Hearst et al. (1964) study the peaks of individual gradients did not always occur at the training stimulus. The peak occurred at the training stimulus for 70% of subjects in the VI 30-s group, for 50% of the VI 120-s subjects, and for 42% of the VI 240-s subjects. Thus, control of responding by the training stimulus occurred to a lesser extent than in the present study.

Generalization Gradients Across Blocks of Testing

Because generalization testing occurs under extinction conditions, the form of the generalization gradient may change over the course of generalization testing (Friedman & Guttman, 1965; Guttman & Kalish, 1956; Hiss & Thomas, 1963; Rilling, 1977; Thomas & Barker, 1964). For this reason, gradients of absolute generalization across blocks 1, 4, 7, and 10 of the test session are shown for individual subjects in Figure 2-3. The pattern of changes in gradient shape across these four blocks of the session is not consistent across subjects. However, a

Figure 2-3. Gradients of absolute generalization across blocks 1 (circles), 4 (squares), 7 (triangles), and 10 (inverted triangles) for subjects trained with a VI 30-s (left panels), a VI 120-s (center panels), or a VI 240-s (right panels) schedule of reinforcement in the presence of a 501-nm light. See Figure 2-1 for definition of absolute generalization.

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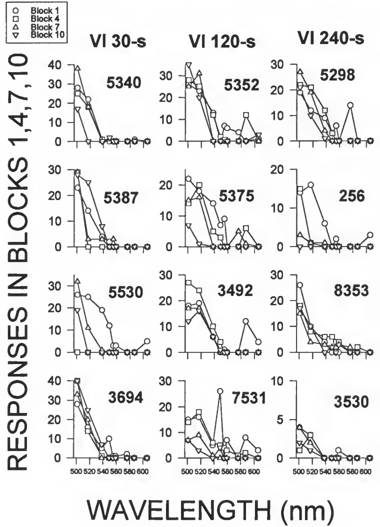


comparison of the gradients for blocks 1 and 10 (circles vs. inverted triangles) shows that frequently the total amount of responding decreased across blocks of the test session. That is, for ten of the twelve subjects (all but 5387 and 3694, both VI 30-s subjects), the absolute number of responses emitted was higher in the first block of the test than in the tenth block, indicating that the amount of responding decreased over the course of testing.

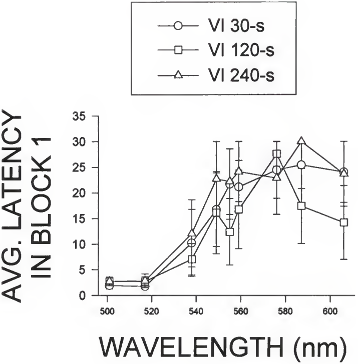
Gradients of relative generalization did not change systematically across blocks 1, 4, 7, and 10 (data not shown) of the test session. Relative generalization gradients were steeper in block 10 than in block 1 for half of the (six) subjects. For five subjects the slopes of gradients of relative generalization were similar for blocks 1 and 10, and for one subject (256) no responses were emitted in the last block (block 10) of the test session.

Other researchers have examined the change in shape of generalization gradients across testing in extinction. They have found that fewer responses are emitted over the course of the extinction session (Friedman & Guttman, 1965; Guttman & Kalish, 1956; Hiss & Thomas, 1963; Honig, Boneau, Burstein, & Pennypacker, 1963; Kalish & Haber, 1963; Rilling, 1977). Some researchers have found that relative generalization does not change over the course of testing in extinction (Guttman & Kalish, 1956; Hiss & Thomas, 1963; Honig et al. 1963). Others have found that relative generalization gradients become steeper during extinction (Friedman & Guttman, 1965; Jenkins & Harrison, 1960; Kalish & Haber, 1963; Thomas & Barker, 1964). Friedman and Guttman (1965) pooled data from a series of experiments designed to examine the effects of discrimination training on generalization gradients and found that the proportion of responding to the training stimulus increased over the course of extinction. Because the total amount of responding decreased over the course of testing, this result reflected a greater decrease in responding in the presence of stimuli not present during training relative to the decrease in responding to the training stimulus itself. Jenkins and Harrison (1960) also obtained this result following the generation of steep gradients after discrimination training, and Thomas and Switalski (1966) observed this relation following single-stimulus training with VI and VR schedules. Kalish and Haber (1963) reanalyzed the data obtained by Guttman and Kalish (1956) and found similar results. That is, the proportion of test responses that occurred in the presence of the training stimulus increased across the test session. Friedman and Guttman (1965) concluded that "the location of the gradient on the test continuum does not appear to change in extinction, but the stimuli remote from the maximum of the curve lose their effectiveness more rapidly than do the stimuli at the center" (p. 266). The present data do not conform to this generalization, however; gradients of relative generalization were steeper in the last block than in the first block of the test for only six subjects.

Latency to Respond in the Presence of the Test Stimuli

Figure 2-4 shows average latency to respond during the generalization test in the first block of the session for all groups of subjects. If responding is under

Figure 2-4. Average latency to respond to each test stimulus in the first block of testing for subjects trained with a VI 30-s (circles), a VI 120-s (squares), or a VI 240-s (triangles) schedule of reinforcement in the presence of a 501-nm light. Average latency for each stimulus is plotted as a function of wavelength of the stimulus in nm. Bars around points represent standard error. (A latency of 30 s was recorded if a subject failed to respond during the 30-s stimulus-on period.)


VI 30-s
VI 120-s
VI 240-s
AVG. LATENCY IN BLOCK 1
35
30
25
20
15
10
5
0
500
520
540
560
580
600
WAVELENGTH (nm)

the control of the training stimulus, the latency should be short in the presence of the training stimulus and longer as the value of the test stimulus becomes progressively different from the value of the training stimulus (Margolius, 1955; Mednick & Freedman, 1960). (Because stimulus-on periods lasted for 30 s, if no response occurred in the presence of a stimulus, a latency of 30 s was recorded.) By this measure, orderly gradients of generalization were obtained. Average latencies to respond were short when the training stimulus and the stimulus presumed to be most similar were presented and increased with the value of the stimulus along the wavelength continuum. These gradients do not differ for the different groups of subjects and provide more evidence that the extent of generalization was similar following training with different VI schedules.

Conclusion

Generalization gradients across the wavelength dimension obtained in the present study were much steeper than gradients obtained by Hearst et al. (1964) across a line-tilt continuum. Whereas gradients of both absolute and relative generalization were flat in the Hearst et al. study for subjects trained with the VI 240-s schedule, the gradients obtained for VI 240-s subjects in the present study were relatively steep. In addition, whereas approximately 150 responses were emitted in the presence of stimuli at the ends of the continuum in the study by Hearst et al., very few responses were emitted in the present study in the presence of stimuli whose values were far from the value of the training stimulus along the dimension of generalization.

Figure 1-2 shows that Haber and Kalish (1963) also obtained a steep gradient of absolute generalization across the wavelength continuum for subjects trained with a VI 15-s, a VI 60-s, or a VI 240-s schedule of reinforcement. A comparison of Figures 1-2 and 2-1 shows that the gradients obtained by Haber and Kalish are very similar in shape to the gradients obtained in the present study. Haber and Kalish also observed almost no responding in the presence of stimuli that differed most from the training stimulus. It may be that the dimension of generalization is a determinant of the shape of generalization gradients. This variable may interact with the schedule of reinforcement used in training to determine the shape of generalization gradients. Alternatively, it may be that stimulus control by line orientation was not as complete in the Hearst et al. study as was stimulus control by wavelength in the present study and in the study by Haber and Kalish. The large number of responses in the presence of stimuli at the ends of the continuum is one indication of the lesser extent of stimulus control in the Hearst et al. study relative to the stimulus control by wavelength. The purpose of Experiment II was to repeat the procedure used by Hearst et al. and replicated in the present experiment using stimuli that differ along a line-tilt continuum in order to test for stimulus control along the dimension of angle of orientation of a line.

CHAPTER 3
EXPERIMENT II

Introduction

Because the results obtained in the present Experiment I did not replicate the relation reported by Hearst et al. (1964) between VI mean interval and extent of generalization, an attempt was made in Experiment II to replicate their procedure even more closely by using different line orientations as the stimuli. Two groups were studied; responding was maintained in the presence of a vertical line by either a VI 30-s or a VI 240-s schedule of food presentation. During generalization testing different orientations of the line were presented.

The dimension of generalization may be a determinant of the shape of generalization gradients (Baron, 1965; Harrison, 1991; Marsh, 1972; Rilling, 1977; Terrace, 1966). Intradimensional discrimination training (i.e., discrimination training wherein the S+ and S- differ along the same stimulus dimension) results in a shift of the peak of the gradient away from S+ in the direction away from S- (peak shift) (Hanson, 1959). According to Marsh (1972), peak shift is reliably obtained following intradimensional discrimination training along the wavelength dimension but is not reliably obtained along the line-orientation dimension. Hearst (1968) conducted intradimensional discrimination training with pigeons in which S+ was a vertical line and S- was a line tilted at a 30-degree angle. Hearst did not observe peak shift, whereas when Marsh repeated the procedure using wavelength of light as the stimulus dimension, peak shift was observed.

Other research has examined the effect of the type of stimulus on the extent of stimulus control that can be established (Baron, 1965; Born & Peterson, 1969; Carter & Eckerman, 1975; Harrison, 1991; Maki & Leuin, 1972; Terrace, 1966). Baron (1965) describes data obtained by Newman (unpublished Masters thesis) whose "findings show greater ease of control by color than by angular orientation" in an experiment on discrimination in which pigeons were the subjects. Different groups of pigeons were trained in a discrimination task in which compound stimuli were presented that differed with respect to one or two stimulus dimensions. Pecks on the positive stimulus (S+) were reinforced; pecks on the negative stimulus (S-) were not. The percentage of total responses to S+ was plotted across ten days of training. A high percentage indicated that the subjects learned the discrimination, whereas 50% indicated chance performance. For one group S+ was the presence of a white line on the key, and S- was the absence of the white line; the background of the key was green for both stimuli. For a second group S+ was a green key with a white line, and S- was a red key with no white line. For a third group the white line was present on both keys; S+ was indicated by a green background, and S- was indicated by a red background. Subjects learned the discriminations in which color was differentially correlated with the availability of reinforcement (Groups 2 and 3) more quickly than when the presence vs. absence of a line (Group 1) was the relevant dimension.

Performance of the last two groups did not differ, a result that indicates that the addition of the line cue did not enhance control by the dimension of color. These data indicate that under some circumstances, stimulus control of key pecking by pigeons may be easier to establish using keylight color (i.e., wavelength) rather than a line dimension (in this case, the presence vs. absence of the line).

Other research shows that pigeons learn complex discriminations involving color more easily than those involving lines. Carter and Eckerman (1975) trained pigeons in a matching-to-sample and a symbolic-matching task using lines and colors as the sample and comparison stimuli. In matching to sample, a sample stimulus is presented (usually on the center key for a pigeon) then comparison stimuli are presented (usually on the keys on either side of the center key). The subject must select from among these comparison stimuli the one that matches (i.e., is the same as) the sample. If the subject selects (i.e., pecks) the comparison stimulus that matches the sample, reinforcement is delivered. In symbolic matching, comparison stimuli are arbitrarily designated "correct" for different sample stimuli. A sample is presented, and reinforcement is delivered if the subject selects the comparison stimulus designated correct for that sample. Carter and Eckerman compared the performance of pigeons on trials in which both sample and comparison stimuli were hues, both were lines, and one was hue and the other was line. They found that color matching was learned quickly, whereas line matching was learned last. Regardless of the sample stimulus dimension, groups with color comparison stimuli learned more quickly than groups with line comparison stimuli. Similarly, regardless of the comparison stimulus dimension, groups with color samples learn more quickly than groups with line samples. "This finding is consistent with the results of other studies which show that it is more difficult to maintain high accuracy during line matching than during color matching" (Carter & Eckerman, 1975, p. 663).

The study to which Carter and Eckerman (1975) refer was an experiment conducted by Maki and Leuin (1972) in which pigeons were trained in a matching-to-sample task involving color and line stimuli. The sample stimulus was one of two colors projected on the key, or one of two orientations of three lines, or a compound stimulus consisting of one color and one orientation. Five seconds after the sample was presented, comparison stimuli appeared on the side keys. A peck on the key on which the matching stimulus was projected was reinforced. The dependent variable was the sample stimulus duration required to maintain matching at an accuracy of 80%. The duration necessary to maintain accurate performance was higher for line matching than for color matching (and was also higher when compound stimuli were presented as samples and comparison stimuli matched one of the stimuli in the compound). That is, if the sample stimulus was a line, it had to remain present longer than did a color sample for accurate matching to be maintained. By this measure, then, color matching was easier to establish than line matching.

Born and Peterson (1969) assessed the extent of stimulus control by color vs. form stimuli. They trained pigeons to peck one key (e.g., the right key) in the presence of one compound stimulus (e.g., a red circle) and the other (left) key in the presence of another compound stimulus (e.g., a green triangle). Then stimulus control by each dimension (i.e., color and form) were assessed by presenting colors and forms separately or by presenting new combinations of color and form. When either color was present, the choice of key and response rate were similar to the choice and rate that would occur when the compound stimulus containing that color was presented in training. When form was presented separately, however, response rates were lower and approximately equal for both keys. When a form signaling reinforcement for responding on one key was presented with a color signaling reinforcement for responding on the other key, responding was controlled almost exclusively by color. Thus, when pigeons were presented with a compound stimulus consisting of a color and a form, control of responding by color was established to a greater extent than control of responding by form.

Taken together, these data suggest that although stimulus control over keypecking by pigeons can be established using lines or forms, control by color, hue, or wavelength may be easier to establish. The steeper gradients observed when wavelength was used as the stimulus dimension (the present Experiment I; Haber & Kalish, 1963) relative to those observed by Hearst et al. (1964) when line orientation was the dimension of generalization may be due to the relative ease of establishing stimulus control by wavelength. The failure to observe a relationship between reinforcement schedule in training and extent of stimulus generalization in Experiment I may, therefore, have been due to the use of wavelength as the stimulus dimension. Experiment II was conducted using stimuli as similar as possible to those used by Hearst et al. (1964).

Method

Subjects

Eight adult, experimentally naive White Carneau pigeons of indeterminate sex were maintained at 75% of their free-feeding weights. All aspects of housing and care were the same as in Experiment I.

Apparatus

The same apparatus was used as in Experiment I, with one modification. The Kodak Wratten filters were removed, and a photographic negative of a picture of eight lines of different orientations was inserted into the projector. Illumination of one lamp behind one line allowed that white line to be projected onto the center of the dark key. The lines were 0.4 cm wide and crossed almost the entire key. The nominal angles of orientation of the lines included vertical (designated 0 degrees) and, measuring clockwise the angle of orientation from the vertical, 22.5, 45, 67.5, 90, 112.5, 135, and 157.5 degrees. The stimulus used in training was the vertical line projected on the key. Because the line that was oriented 157.5 deg. from the vertical was actually 22.5 degrees from the vertical, but in the opposite direction of the line designated as 22.5 degrees from the vertical, it was presumed to be as similar to the vertical line as the 22.5-degree line. The same notion applied to the 45- and 135-degree lines and for the 67.5-

and 112.5-degree lines, whereas the line angled 90 degrees from the vertical was horizontal. For the purpose of symmetry around the central point of the gradient (i.e., the 0-degree training stimulus), the data generated in the presence of the horizontal line are presented twice, once on each side of the gradient. Because the situation of the negative in the projector was slightly concave, the actual angles of orientation of the lines were, as measured with a protractor, -0.5, 21, 52, 70, 91, 112, 138, and 156 degrees from the true vertical, respectively. The actual angles of orientation, measured in degrees from the training stimulus, are therefore 0, 21.5, 52.5, 70.5, 91.5 (or -88.5), 112.5 (or -67.5), 138.5 (or -41.5), and 156.5 (or -23.5) degrees.

Procedure

Preliminary and VI training. The same procedures were used as in Experiment I, except that the vertical line, rather than the 501-nm light, was projected onto the key during key-peck shaping, FR 1, and VI training conditions. In this experiment adaptation lasted for one 30-min session, and magazine training lasted for one to two sessions, each of which lasted until about 30 min elapsed or approximately 40-50 food presentations occurred. Key peck shaping lasted for one session (between 5 and 20 min until the pigeon pecked the key), and the FR 1 schedule was in effect for 100 reinforcements (two sessions of 50 reinforcements each). Only two groups were studied; one group was trained with a VI 30-s schedule, and the other group responded under a VI 240-s schedule of food presentation. All subjects experienced ten sessions of VI training, except one pigeon in the VI 30-s group (Subject 4415), which experienced 11 sessions. The same response and reinforcement measures were collected as in Experiment I.

Generalization testing. Testing was conducted in the same way as in Experiment I. Training conditions were in effect for the first 10 min of the testing session. During this time the vertical line was projected on the key, and the schedule of reinforcement was in effect. After this preliminary period, testing was conducted in extinction with different line orientations as the test stimuli. Eight orientations of the line were used as stimuli; therefore, each of the ten blocks consisted of eight stimulus presentations, determined as were stimulus presentations in Experiment I. Again, the same response and reinforcement measures were collected as in Experiment I.

Results and Discussion

Training

Responding was maintained following the transition from the FR 1 to the VI schedule. Response rates increased across the first few or several sessions then stabilized for all subjects. Response rates were generally higher for subjects trained with the VI 30-s schedule than for subjects trained with the VI 240-s schedule. The average response rate for the last session of training was 50.4 responses per min for the VI 30-s group and 25.5 responses per min for the VI 240-s group. Response rates during the preliminary period of testing were very similar to rates during the last session of training for individual subjects. The average response rate for the preliminary period of the test session was 52.5

responses per min for the VI 30-s group and 29.4 responses per min for subjects trained with the VI 240-s schedule. Obtained reinforcement rates approximated programed reinforcement rates by the third session of training for seven subjects. For Subject 4552 (a VI 240-s subject) reinforcement rate ranged from 0.08 to 0.13 for the first five training sessions then increased to between 0.21 and 0.27 reinforcers per min during the last five sessions.

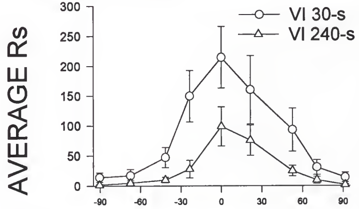
Absolute and Relative Generalization and Index of Gradient Slope

Figure 3-1 shows gradients of average absolute (upper panel) and relative (lower panel) generalization for the two groups of subjects. The upper panel shows that subjects trained with the VI 30-s schedule generally emitted a greater number of responses during the generalization test. Although the absolute generalization gradient for the VI 30-s subjects is displaced upward relative to the gradient for the VI 240-s subjects, the shapes of the gradients (i.e., the slopes of the gradients on either side of the value of the training stimulus) are similar. A two-factor, repeated-measures ANOVA with VI mean interval as the between-subjects factor and stimulus value as the within-subjects factor indicates that the differences between the two groups are not statistically significant ($F=4.737$, $p>.05$, $df=1$) by conventional standards. There was a statistically significant effect of line tilt ($F=14.452$, $p<.05$, $df=7$) and an interaction effect that was significant ($F=2.393$, $p<.05$, $df=7$).

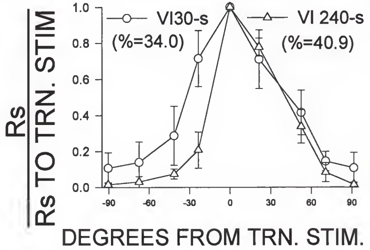
To facilitate comparison of the two gradients by normalizing responding, gradients of relative generalization are shown for the two groups of subjects in the

Figure 3-1. Gradients of average absolute (upper panel) and relative (lower panel) generalization for subjects trained with a VI 30-s (circles) or a VI 240-s (triangles) schedule of reinforcement in the presence of a vertical line. Absolute generalization (upper panel) refers to the total number of responses emitted in the presence of each test stimulus as a function of angular degrees from the training stimulus. Relative generalization (lower panel) refers to the total number of responses emitted in the presence of each test stimulus expressed as a proportion of the number of responses to the training stimulus. Bars around control points represent standard error. Also shown are average indexes of gradient slope (numbers in parentheses), or the percentage of total test responses that were emitted in the presence of the training stimulus.

ABSOLUTE GENERALIZATION



RELATIVE GENERALIZATION



lower panel of Figure 3-1, as are the average indexes of gradient slope (numbers in parentheses). The right halves of the gradients are virtually identical for the two groups of subjects, whereas the left half of the gradient for subjects trained with the VI 240-s schedule is somewhat steeper than that for the VI 30-s subjects. A two-factor, repeated-measures ANOVA indicates no statistically significant differences between groups due to the main effect of VI mean interval ($F=1.536$, $p>.05$, $df=1$). There was a statistically significant effect of stimulus value ($F=30.968$, $p<.05$, $df=6$) and a significant interaction effect ($F=4.003$, $p<.05$, $df=6$).

The average index of gradient slope is similar for the two groups. The average index is 34.0% for the VI 30-s group, and individual indexes range from 18.4 to 60.4% The average index of gradient slope is 40.9% for the VI 240-s group, and values range from 32.7 to 48.9% for individual subjects. By this index, gradient slopes vary over a wider range for the VI 30-s subjects than for the VI 240-s subjects, and there is no systematic difference between the two groups with respect to this measure.

The gradients shown in Figure 3-1 are similar in shape to those from Experiment I in which wavelength of light was the stimulus dimension (see Figure 2-1), although a direct comparison is difficult given the difference in dimension of generalization. A comparison of these figures with Figure 1-1 shows that average gradients of absolute and relative generalization obtained in the present study were relatively steep, regardless of the dimension of generalization tested.

Whereas the gradients obtained by Hearst et al. (1964) were flat for the VI 240-s subjects, those obtained in the present study for subjects trained with a VI mean interval of 240 s were not, even when the dimension of generalization was line-tilt and the spacing of stimuli was almost identical to that in the study by Hearst et al.

Another difference in results is that in the present study, only 0 to 58 responses were emitted in the presence of stimuli at the ends of the continuum (i.e., 91.5 or -88.5, -67.5, and 70.5 degrees from the training stimulus), whereas in the Hearst et al. (1964) study, pigeons emitted about 150 responses, on average, in the presence of stimuli at the ends of the continuum (i.e., 90, -67.5, and 67.5 degrees from the training stimulus). Other researchers have published gradients of generalization along a line-orientation continuum that show a large number of responses in the presence of stimuli at the ends of the continuum (Hearst & Koresko, 1968; Honig, Boneau, Burstein, & Pennypacker, 1963; but see Farthing & Hearst, 1968, described below).

Hearst and Koresko (1968) trained different groups of pigeons with a VI 60-s schedule for different numbers of sessions according to the procedure used by Hearst et al. (1964). (This experiment will be described in detail in Chapter 4.) They constructed absolute generalization gradients by plotting the total number of responses emitted in the presence of the test stimuli by all subjects in a group. The number of responses emitted in the presence of stimuli whose values were furthest from the training stimulus on the line-tilt continuum varied from approximately 400 to 1200 responses (an average of 50 to 150 responses in 50 min of testing, or 37.5 min in the presence of the test stimuli).

Honig et al. (1963) performed two experiments wherein they conducted discrimination training with pigeons then tested for generalization to different line tilts. (Their Experiment II was a replication of their Experiment I with subjects that were experimentally naive.) For one group the presence of a vertical line on the key (S+) was correlated with a VI 60-s schedule, and the absence of the line (S-) was correlated with extinction. For the other group the contingencies were reversed. The gradient of absolute generalization for the group from Experiment I whose S+ was the presence of the vertical line was comparable in shape to the gradient reported by Hearst et al. (1964) for subjects trained with a VI 60-s schedule. Between 300 and 400 responses were emitted in the presence of the training stimulus, and more than 100 responses were emitted in the presence of stimuli whose values were located at the end of the continuum. This occurred over the course of a 56-min test session, which consisted of 42 min in the presence of the test stimuli. (Fewer responses were emitted by the subjects in Experiment II; approximately 150 responses occurred in the presence of the training stimulus, and 40 responses occurred to the stimulus at the end of the continuum. Relative generalization gradients were similar for the two experiments.)

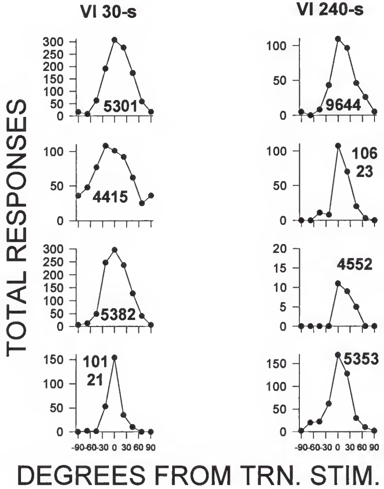
Neither Lyons (1969) nor Davis (1971) could obtain inhibitory stimulus control using line orientation as the dimension of inhibitory generalization. According to Rilling (1977), Drexler and Terrace (unpublished) believe that this failure was due to a large number of responses in the presence of S-, a result that indicates a lack of inhibitory control by S-. The fact that Hearst (1968, described above) did not observe peak shift using line orientation as the stimulus dimension, whereas Marsh (1972, also described above) did using Hearst's (1968) procedure and wavelength of light as the stimulus dimension provides further support for the notion that stimulus control of pigeons' keypecking by wavelength of light is easier to establish than is stimulus control of pecking by line orientation.

Given the data of the present experiment, the establishment of stimulus control by line orientation is not as difficult as the data described above might suggest. Approximately 100 fewer responses, on average, were emitted during testing in the present study compared to the study by Hearst et al. (1964) to stimuli whose values are at the ends of the continuum. Generalization gradients are steep in the present study, even for subjects trained with the VI 240-s schedule of reinforcement. In addition, Farthing and Hearst (1968) did not have trouble establishing inhibitory stimulus control using line tilt. After one, two, or four sessions of discrimination training, an average of approximately 40 to 60 responses occurred in the presence of S- (a black line on a white key) during the 56-min test session (42 min in the presence of the test stimuli). After eight or 16 sessions, however, fewer than five responses were emitted, on average, in the presence of S-. Further evidence that stimulus control by line tilt is not difficult to establish is shown by the fact that Bloomfield (1967) did observe peak shift following discrimination training wherein S+ and S- were different orientations of a line. It remains to be seen why Hearst et al. (1964) obtained the data they reported and why some researchers have established control of responding by line orientation more easily than others. This issue will be discussed in Chapter 5.

Average generalization gradients are representative of individual-subject gradients, which are shown in Figure 3-2 for absolute generalization for all subjects. Absolute generalization gradients show that three of the four subjects trained with the VI 30-s schedule responded more during the generalization test than did subjects trained with the VI 240-s schedule. The average number of responses emitted in the test was 728 and 255 responses for the VI 30-s and VI 240-s groups, respectively. Individual-subject response totals ranged from 255 to 1092 responses for the VI 30-s group and from 25 to 443 responses for the VI 240-s group. The shapes of individual gradients of both absolute and relative generalization (data not shown) are similar. Subject 4415 (from the VI 30-s group) emitted many more responses in the presence of stimuli at the ends of the continuum than did the other subjects, and the peak of this subject's gradient did not occur at the value of the training stimulus. Generally, absolute and relative generalization gradients are similar for the two groups of subjects, except that the left side of the gradients appear slightly steeper for the VI 240-s subjects than for subjects trained with the VI 30-s schedule. (This difference is also noticeable in the gradients for average generalization shown in Figure 3-1.)

Figure 3-2. Gradients of absolute generalization for individual subjects trained with a VI 30-s (left panels) or a VI 240-s (right panels) schedule of reinforcement in the presence of a vertical line. See Figure 3-1 for definition of absolute generalization.

ABSOLUTE GENERALIZATION



Generalization Gradients Across Blocks of Testing

Figure 3-3 shows gradients of absolute generalization for individual subjects across blocks 1, 4, 7, and 10 of the test session. For all subjects there was less responding in the last block of the session (inverted triangles) than in the first(circles), a result that is consistent with the finding that the absolute level of responding decreases over the course of testing in extinction (see discussion of Figure 2-3, Experiment I). Four subjects (5301, 10121, 4552, and 5353) did not respond in the presence of the training stimulus during the last block of the test session. For these subjects during the last block of testing responses occurred in the presence of no more than two stimuli not used in training, and the total number of responses did not exceed five responses for any one stimulus. For three of the other four subjects (all but 5382) relative generalization gradients (data not shown) were steeper for the last block of the session than for the first.

Latency to Respond in the Presence of the Test Stimuli

Figure 3-4 shows average latency to respond in the first block of testing in the presence of each test stimulus. An orderly gradient of generalization exists if the latency to respond in the presence of the training stimulus is short and increases as a function of degrees from the training stimulus. In general, this is the case for both groups of subjects; average latency in the presence of the training stimulus was short, and latency increased as the number of degrees between training and test stimulus increased. The right halves of the generalization gradients for latency to respond are virtually identical for the two

Figure 3-3. Gradients of absolute generalization across blocks 1 (circles), 4 (squares), 7 (triangles), and 10 (inverted triangles) for subjects trained with a VI 30-s (left panels) or a VI 240-s (right panels) schedule of reinforcement in the presence of a vertical line. See Figure 3-1 for definition of absolute generalization.

ABSOLUTE GENERALIZATION

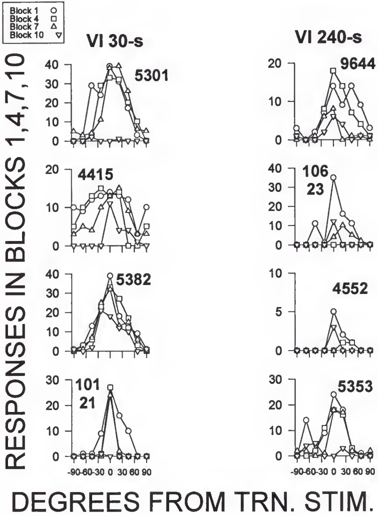
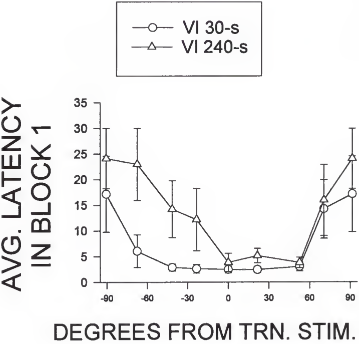


Figure 3-4. Average latency to respond to each test stimulus in the first block of testing for subjects trained with a VI 30-s (circles) or a VI 240-s (triangles) schedule of reinforcement in the presence of a vertical line. Average latency for each stimulus is plotted as a function of angular degrees from the training stimulus. Bars around points represent standard error. (A latency of 30 s was recorded if a subject failed to respond during the 30-s stimulus-on period.)


VI 30-s
VI 240-s
AVG. LATENCY IN BLOCK 1
35
30
25
20
15
10
5
0
-90
-60
-30
0
30
60
90
DEGREES FROM TRN. STIM.

groups of subjects, whereas the left halves indicate that subjects trained with the VI 30-s schedule began to peck the key more quickly than subjects trained with the VI 240-s schedule when lines were presented whose orientations were -23.5, -41.5, and -67.5 degrees from the orientation of the line used in training. Thischaracterization of generalization is very similar to that of Figure 3-1 where the extent of generalization is indicated by the number of responses (absolute generalization, upper panel) and as a proportion of the number of responses emitted in the presence of the training stimulus (relative generalization, lower panel). Latency to respond appears to be a valid measure of generalization in that it results in a characterization that is similar to the pattern resulting when absolute and relative generalization are described.

Overall, the shapes of the gradients obtained in the present study are very similar, regardless of the stimulus dimension or the schedule of reinforcement used in training (compare Figures 2-1 and 3-1). The present gradients are very different in shape from those obtained by Hearst et al. (1964) for subjects trained with a VI 240-s schedule. Although stimulus control by wavelength may be easier to establish than control by line orientation when pigeons are subjects and the response is a key peck, results from the present experiments show that generalization gradients obtained using the present procedure can be very similar whether wavelength of light or line orientation is the dimension of generalization.

Conclusion

The results from Experiment II are consistent with those from Experiment I, which show that the inverse relation between VI mean interval and steepness of gradient slope reported by Hearst et al. (1964) is not a robust phenomenon. Generalization gradients were steep following training with either a VI 30-s or a VI 240-s schedule of reinforcement, and this result occurred regardless of the stimulus dimension studied. The dimension of generalization may not be an important determinant of the shape of a generalization gradient, at least under the conditions of the present study. It appears that the schedule of reinforcement used in single-stimulus training has little effect on the extent of generalization. In addition, because the total number of reinforcers obtained by subjects trained with different VI schedules differed but the gradients were similar, the number of reinforcers obtained during single-stimulus training may not be an important determinant of the shape of generalization gradients, at least under the present circumstances (i.e., when generalization testing follows ten sessions of training via the present procedure).

CHAPTER 4
EXPERIMENT III

Introduction

The original purpose of the present set of experiments was to examine whether the total number of reinforcers earned during training was the variable responsible for the greater extent of generalization following training with longer VI schedules than following training with shorter VI schedules in the study by Hearst et al. (1964). This relation was not replicated in the present set of experiments. However, Experiment III was conducted to test whether the amount of training was a determinant of the extent of generalization. Eckerman (1969, described in the present Experiment I, Introduction) provided evidence that equivalent levels of stimulus control (defined as differential responding in the presence of S+ vs. S-) were established after an equal number of reinforcers in groups that experienced discrimination training in which different probabilities of reinforcement were associated with S+. This result indicates that under some conditions, the total number of reinforcers earned (or the amount of training) may be a more important determinant of the development of stimulus control than is frequency of reinforcement.

The usual procedure for conducting experiments on generalization following single-stimulus training is to train subjects to respond in the presence of a particular stimulus then test for generalization following a specific number of training sessions (usually ten to 11) (Guttman & Kalish, 1956; Harrison, 1991; Rilling, 1977; Terrace, 1966). When other types of operant-conditioning experiments are conducted, subjects are trained until some measure of responding (e.g., response rate, latency) is stable; that is, the level does not change systematically from session to session (i.e., does not show a trend), and the variability of responding is minimal (i.e., the measure of responding does not change dramatically from session to session). Then the effects of independent variables are assessed (Sidman, 1960). In the present Experiment III four pigeons were trained to peck a key under conditions identical to those for pigeons in the VI 240-s group in Experiment I, with one modification. These subjects were trained until their response rates became stable according to a stability criterion described by Perone (1991). Then generalization testing was conducted. Data from these pigeons were compared with data from the pigeons in the VI 240-s group from Experiment I to see if their more prolonged training would produce generalization gradients that differed from those of subjects who experienced only ten sessions of training. That is, part of Experiment I was replicated directly except that the total number of training sessions and, therefore, the total number of reinforcers obtained during training differed across subjects.

The amount of training, including both time spent in the training condition and the total number of reinforcers obtained, appears to be a determinant of the shape of generalization gradients. According to Dinsmoor (1995a), gradients of stimulus generalization become steeper with more prolonged training. For example, Hearst and Koresko (1968) replicated the procedure used by Hearst et al. (1964) for subjects trained with a VI 60-s schedule of food presentation. Four groups of pigeons experienced two, four, seven, or 14 sessions of training with a VI 60-s schedule of reinforcement in the presence of a vertical line. Generalization testing was conducted in extinction. The authors found that the slopes of both absolute and relative generalization gradients became steeper with increased single-stimulus training, a result that is consistent with the hypothesis that the number of reinforcers obtained during training may have been responsible for the steeper slopes obtained by Hearst et al. (1964) when the VI mean interval was shorter. This result is also consistent with the notion that generalization gradients become steeper with more prolonged VI training. That is, gradients of absolute and relative generalization were steeper for subjects who experienced more training than for subjects who experienced less training with the same schedule of reinforcement.

Schadler and Thomas (1972) also examined the shapes of generalization gradients for subjects with differing amounts (0, 5, 10, or 20 min) of single-stimulus training (although this training followed training in the presence of a stimulus along a different stimulus dimension). They found that gradients of absolute and relative generalization (defined as the percentage of total responses in the presence of each test stimulus) were steeper for subjects with at least 10 min of experience with a VI 60-s schedule of reinforcement in the presence of the training stimulus (a white line on a black key). The authors concluded that when response strength is established at the time of testing (subjects first experienced seven sessions of training with a VI 60-s schedule in the presence of a white key in order to establish key pecking before single-stimulus training in the presence of the line), stimulus control is acquired rapidly (Schadler & Thomas, 1972). According to Rilling (1977), "once the response is acquired, control by a stimulus associated with reinforcement may develop in a matter of minutes" (p. 454). Farthing and Hearst (1968; described in Chapter 3) also found that gradients of inhibition were steeper following four, eight, or 16 sessions than following one or two sessions of training.

Hearst and Koresko (1968), however, cite evidence that more prolonged training with a VI schedule (e.g., more than 20 sessions) may result in a flattening of the generalization gradient. Friedman and Guttman (1963; as cited by Hearst & Koresko, 1968) "observed that subjects tested for generalization after 30 days of VI training yield flatter relative generalization gradients than subjects trained for the usual 1-2 weeks" (Hearst & Koresko, 1968, p. 137). Hearst and Koresko explain these results by saying that "locked rate" or proprioceptive control (control of responses by previous responses) may become a factor in prolonged single-stimulus training and may reduce the extent of exteroceptive stimulus control.

Other researchers have reported that generalization gradients become flatter with more prolonged training (Margolius, 1955; Mednick & Freedman, 1960; Olson & King, 1962). Olson and King (1962) compared generalization gradients along a luminosity continuum for pigeons trained to peck a key that was illuminated with a particular brightness of white light. Different groups were trained for two, five, ten, or 20 sessions with a VI 60-s schedule according to the Guttman and Kalish (1956) procedure. During generalization testing different luminosities of the key were tested. Subjects in the group that experienced two sessions of training were specifically selected for their high response rates. Results showed that gradients of average relative generalization were steepest for the subjects trained for five sessions. The gradient for subjects trained for ten sessions was similar to that for subjects trained for two sessions, and the relative generalization gradient for the 20-session group was the flattest. These results are consistent with the possibility that generalization gradients become steeper as training continues then become flatter with more prolonged VI training.

Margolius (1955) examined the relation between extent of generalization and the total number of reinforcers earned during training. He trained rats to travel down a runway and measured the latency to push open a door that led to food that was located in a 79-cm^2 circle (the training stimulus). Different groups of rats received 0, 4, 16, 64, 104, or 164 reinforced trials following acquisition of the response. The groups that received 0-104 training trials were divided into groups that were tested with one stimulus each, either the training stimulus or a circle of a different size. Gradients of stimulus generalization were constructed by plotting the reciprocal of the average latency to push the door open for groups of subjects tested with circles of different areas. The group trained for 164 trials was tested with the training stimulus. Hiss and Thomas (1963) compared this method of obtaining generalization gradients with the method used in the present experiments wherein each subject is presented with each test stimulus, and responding is recorded in the presence of each stimulus. They found that generalization gradients were similar in shape for the two methods.

Margolius (1955) found that absolute generalization increased as a function of the number of training trials and that "peak performance in terms of the latency criterion ... [was] achieved by 104 trials" (p. 107). That is, average latency did not differ significantly for the groups experiencing 104 and 164 reinforced training trials. By the latency measure, then, it appears that subjects in the 104-trial group had been trained to asymptotic (i.e., stable) performance, and these subjects showed the greatest extent of generalization to stimuli not present during training. A gradient of absolute generalization was also constructed by plotting the average number of responses emitted in the presence of the different stimuli. The number of responses emitted in the presence of the training stimulus increased, and absolute generalization gradients became flatter, with increased training experience. The height of the gradient also increased with an increased number of training trials (Margolius, 1955).

This assortment of results appears to indicate that the steepness of gradients of stimulus generalization is a function of the amount of training, up to some maximum number of sessions (Hearst & Koresko, 1968; Schadler & Thomas, 1972) or reinforcers (Margolius, 1955). More extensive training with a

VI schedule of reinforcement may result in a flattening of the gradient (Friedman & Guttman, 1963, as cited by Hearst & Koresko, 1968; Olson & King, 1962). Experiment III was conducted to examine the relation between amount of training with a VI 240-s schedule in the presence of a particular wavelength of light and the extent of generalization to stimuli that differ along the wavelength dimension.

Method

Subjects

Four adult, experimentally naive White Carneau pigeons of indeterminate sex were maintained at 75% of their free-feeding weights. All aspects of housing and care were the same as in Experiment I.

Apparatus

The apparatus was identical to that used in Experiment I.

Procedure

Preliminary and VI training. The same procedures were used as in Experiment I. In this experiment adaptation lasted for one 20- to 30-min session, and magazine training lasted for one to two sessions of approximately 40 food presentations or 30 min. Key peck shaping lasted for one session, and the FR 1 schedule was in effect for 100 to 150 reinforcements (50 reinforcements per session). Only one group was studied; the schedule in effect was VI 240-s, and sessions were conducted until stability criteria were met. These stability criteria have been described by Perone (1991) and are based on response rates from nine consecutive sessions. Nine consecutive sessions are divided into groups of three, and the mean response rate for each group of three sessions is calculated. If these means do not show a decreasing or increasing trend, and if they do not differ from the overall mean response rate for all nine sessions by more than 10%, the response rates are considered stable. When these stability criteria were met, testing began. Stability criteria were met following 40, 40, 57, and 32 sessions for Subjects 2255, 10575, 1352, and 10670, respectively. The same response and reinforcement measures were collected as in Experiment I.

Generalization testing. Testing was conducted in the same way as in Experiment I. Again, the same response and reinforcement measures were collected as in Experiment I.

Results and Discussion

Four subjects experienced training with a VI 240-s schedule of reinforcement in the presence of a 501-nm keylight until response rates met a stability criterion (described above). The data from these subjects are compared with those from subjects from Experiment I that experienced ten sessions of training under the same conditions (i.e., the VI 240-s group). The behavior of the latter subjects was described in detail in Chapter 2; therefore, the following description of results will focus on the behavior of the subjects whose responding stabilized. Results from Experiment I will be elaborated only for comparison purposes.

Training

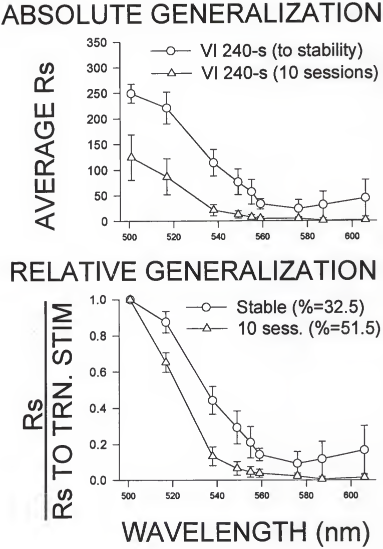
Responding was maintained following the transition from the FR 1 to the VI 240-s schedule for all four subjects. (Responding was maintained for three subjects in the VI 240-s group of Experiment I; see Chapter 2, Results and Discussion.) Response rates for the four subjects whose response rates stabilized were lower during the first several sessions of training than at the end of training. Response rates increased gradually across training sessions then stabilized after 32 (9630), 40 (2255), 40 (10575), or 57 (1352) sessions.

Response rates during the last session of training are representative of stable responding at the end of training for subjects trained to stability. The average response rate (36.0 responses per min) was higher than the average response rate for the VI 240-s subjects from Experiment I (18.0 responses per min) that experienced only ten sessions of training. For subjects trained to stabiltity response rates were lower during the tenth session of training than at the end of training. The average response rate after ten sessions of training was 20.5 responses per min for subjects trained to stability. This rate is similar to the rate of subjects from Experiment I. Response rates during the preliminary period of the test session correlated well with rates during the last session of training. The average response rate was 34.3 and 25.7 responses per min for subjects trained to stability and subjects trained for ten sessions, respectively. Reinforcement rates were similar to the programed rate of reinforcement for three subjects trained to stability from the beginning of training. For Subject 2255 reinforcement rates in the first five sessions ranged from 0.08 to 0.13 reinforcers per min then increased and were maintained at approximately the programed rate of reinforcement.

Absolute and Relative Generalization and Index of Gradient Slope

Figure 4-1 shows gradients of average absolute (upper panel) and relative (lower panel) generalization and average index of gradient slope (numbers in parentheses) for subjects trained until their response rates met the stability criteria and for the subjects from Experiment I that were trained for ten sessions. The subjects that experienced more than ten sessions of training responded more during testing in the presence of the training stimulus and in the presence of test stimuli not present during training (upper panel). That is, the gradient is displaced upward relative to the gradient for subjects trained for ten sessions. (Note that error bars do not overlap except for stimuli whose values are far from the training stimulus on the wavelength continuum.) Besides the upward displacement of the gradient for subjects trained to stability, the shapes of the gradients look similar. A two-factor ANOVA of the effects of amount of training (between-subjects factor) and stimulus value (within-subjects factor) indicates that the difference between groups is statistically significant ($F=8.558$, $p<.05$, $df=1$). There is also a signficant effect of wavelength ($F=29.244$, $p<.05$, $df=8$) and a statistically significant interaction effect ($F=3.184$, $p<.05$, $df=8$). Because the overall level of responding during the test differs for the two groups, a comparison of relative generalization gradients (lower panel) seems more appropriate for

Figure 4-1. Gradients of average absolute (upper panel) and relative (lower panel) generalization for subjects trained with a VI 240-s schedule of reinforcement in the presence of a 501-nm light. Subjects were trained for ten sessions (triangles; data from the VI 240-s group of Experiment I) or until their response rates were stable (circles). Absolute generalization (upper panel) refers to the total number of responses emitted in the presence of each test stimulus as a function of wavelength of the stimulus in nm. Relative generalization (lower panel) refers to the total number of responses emitted in the presence of each test stimulus expressed as a proportion of the number of responses to the training stimulus. Bars around control points represent standard error. Also shown are average indexes of gradient slope (numbers in parentheses), or the percentage of total test responses that were emitted in the presence of the training stimulus.



ABSOLUTE GENERALIZATION

RELATIVE GENERALIZATION

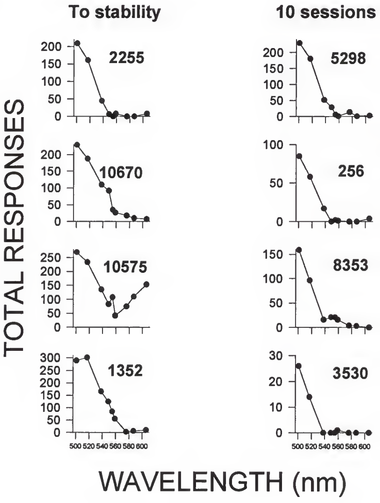
assessing the extent of generalization for the two groups. The extent of relative generalization appears to be slightly greater for the subjects that experienced more training. A two-factor ANOVA of the main effect of training amount indicates that the difference between groups in extent of relative generalization is statistically significant (F=6.951, p<.05, df=1). There was a statistically significant main effect of wavelength (F=47.193, p<.05, df=7), but the interaction effect was not signficant (F=1.302, p>.05, df=7).

Using index of gradient slope as a measure of gradient steepness, the gradient for the subjects that experienced more training is flatter than the gradient for the subjects that experienced ten training sessions. That is, 32.5% of test responses occurred in the presence of the training stimulus for the group trained to a stability criterion, whereas 51.5% of responses occurred in the presence of the training stimulus for subjects trained for only ten sessions. Individual indexes of gradient slope, however, overlap for the two groups of subjects, indicating that this relation is not very dramatic, either. Indexes range from 22.3 to 47.8% for subjects with more training and from 44.5 to 63.4% for subjects trained for ten sessions.

Gradients of absolute generalization are shown for individual subjects in Figure 4-2. The average gradients are representative of gradients for individual subjects, and indexes of gradient slope appear to be valid measures of the steepness of generalization gradients (that is, higher indexes correspond with

Figure 4-2. Gradients of absolute generalization for individual subjects trained with a VI 240-s schedule of reinforcement in the presence of a 501-nm light until their response rates were stable (left panels) or for ten sessions (right panels). See Figure 4-1 for definition of absolute generalization.

ABSOLUTE GENERALIZATION



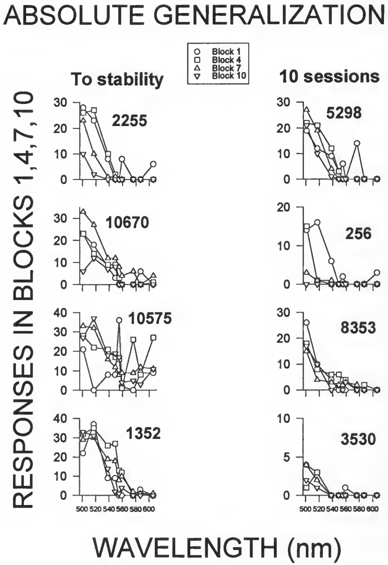
steeper slopes, and lower indexes correspond with flatter gradients). Three of the four subjects (all but 2255) that experienced more than ten sessions of training (left panels) responded more during the test than did subjects trained for ten sessions (right panels). The former group responded an average of 851 timesduring the test, and reponse totals ranged from 437 to 1210 responses. The subjects trained for ten sessions responded an average of 265 times during the test, and their response totals ranged from 41 to 515 responses. An unpaired t-test comparing the means for the two groups indicates that the difference between groups is statistically significant at the $p<.05$ level ($t=2.925$, $df=6$). Subject 2255 emitted fewer responses than the other subjects trained to stability, and the generalization gradient for this subject is very similar to the gradients for subjects trained for only ten sessions. The other three subjects in the stability group generalized more (i.e., responded more in the presence of stimuli not present during training) than the subjects trained for ten sessions. The absolute generalization gradient for Subject 10575 is an outlier, however, in that this subject responded more to stimuli whose values are far from the value of the training stimulus on the wavelength continuum than it did to stimuli whose values are in the middle of the continuum near the value of the training stimulus. A two-factor, repeated-measures ANOVA excluding this subject's data shows that differences between the two groups were not statistically significant ($F=6.018$, $p>.05$, $df=1$). There were still significant effects of wavelength ($F=27.907$, $p<.05$, $df=8$) and of wavelength-training amount interaction ($F=4.065$, $p<.05$, $df=8$). In general, then, subjects trained for more than ten sessions responded more often during the test, and the three subjects that responded most during the test showed more absolute generalization than the other subjects (subjects in the ten-session group plus Subject 2255).

Relative generalization gradients result in the same characterization as does index of gradient slope. That is, three subjects (all but Subject 2255) in the stability group showed more relative generalization (data not shown) and had lower indexes of gradient slope (range=22.3 to 32.0%) than did subjects in the ten-session group (range=44.5 to 63.4%) plus Subject 2255 (47.8%). An ANOVA excluding data from Subject 10575 shows that the main effect of training amount (trained to stability vs. trained for ten sessions) was not statistically significant ($F=5.768$, $p>.05$, $df=1$). Effects of wavelength ($F=76.254$, $p<.05$, $df=7$) and interaction ($F=3.743$, $p<.05$, $df=7$) were significant. These data may indicate that prolonged training tends to result in more responding during the generalization test. When this is true, gradient slopes for individual subjects are somewhat flatter than when fewer responses are emitted in the generalization test (e.g., 2255). This possibility will be examined in Chapter 5 (Figure 5-1).

Generalization Gradients Across Blocks of Testing

Figure 4-3 shows gradients of absolute generalization for individual subjects across blocks 1, 4, 7, and 10 of the test session. A comparison of absolute generalization gradients for the first (circles) and tenth (inverted triangles) block of testing shows that six of the eight subjects (all but 10575 and 1352, both

Figure 4-3. Gradients of absolute generalization across blocks 1 (circles), 4 (squares), 7 (triangles), and 10 (inverted triangles) for subjects trained with a VI 240-s schedule of reinforcement in the presence of a 501-nm light until their response rates became stable (left panels) or for ten sessions (right panels). See Figure 2-1 for definition of absolute generalization.

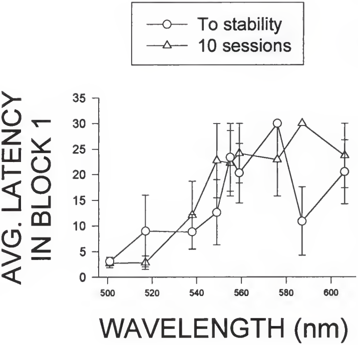

ABSOLUTE GENERALIZATION
Block 1
Block 4
Block 7
Block 10
To stability
10 sessions
2255
10670
10575
1352
5298
256
8353
3530
RESPONSES IN BLOCKS 1,4,7,10
0
5
10
20
30
40
500 520 540 560 580 600
WAVELENGTH (nm)

subjects that were trained to stability) responded less during the tenth than during the first block of testing. Relative generalization gradients across blocks of the session (data not shown) show no systematic differences between groups or consistent trends across the session. The relative generalization gradients for two subjects trained to stability (2255 and 1352) and two subjects trained for ten sessions (5298 and 3530) were steeper in the last block of the session than in the first. Subject 256 (a subject trained for ten sessions) did not respond during the last block of testing, and the other subjects showed no consistent trends in the extent of relative generalization across blocks of the session.

Latency to Respond in the Presence of the Test Stimuli

Figure 4-4 shows the average latency to respond on the first presentation of each test stimulus for the two groups of subjects. Orderly gradients of generalization exist for both groups of subjects. That is, the latency to respond in the presence of the training stimulus was short, and average latency increased as the distance between the value of the training stimulus and the value of the test stimulus along the dimension of generalization increased. The gradients are almost identical for the two groups of subjects. Average latencies to respond were similar, and error bars overlap at each stimulus value. By this measure of generalization, then, subjects that experienced ten sessions of single-stimulus training with a VI 240-s schedule in effect generalized to an extent similar to subjects trained until their response rates became stable. Again, latency to

Figure 4-4. Average latency to respond to each test stimulus in the first block of testing for subjects trained with a VI 240-s schedule of reinforcement in the presence of a 501-nm light. Subjects were trained for ten sessions (triangles) or until their response rates were stable (circles). Average latency for each stimulus is plotted as a function of wavelength of the stimulus in nm. Bars around points represent standard error. (A latency of 30 s was recorded if a subject failed to respond during the 30-s stimulus-on period.)


To stability
10 sessions
AVG. LATENCY IN BLOCK 1
35
30
25
20
15
10
5
0
500
520
540
560
580
600
WAVELENGTH (nm)

respond appears to be a valid measure of generalization in that it varies as an orderly function of the value of the test stimulus along the stimulus continuum.

Conclusion

Results from the present experiment suggest that more prolonged training tends to result in higher response rates at the end of training than does lessprolonged training and in more responding during the generalization test (this was true for three of four subjects in the present study). The three subjects that responded most in the generalization test also showed the most extensive generalization, and these were subjects trained for more than ten sessions. Although the differences in extent of relative and absolute generalization were statistically significant, the effect of amount of training (training to stability vs. training for ten sessions) was not dramatic. When data from an outlier subject were excluded from the analyses, the differences were no longer statistically significant. The fact that training subjects until a stability criterion is met results in gradients that are similar in shape following training for ten sessions has implications for the conduction of experiments on generalization. This result shows that ten sessions of training is probably sufficient for obtaining valid measures of generalization.

CHAPTER FIVE
DISCUSSION

Summary of Results

In the present set of experiments, orderly gradients of generalization were obtained following single-stimulus training with a VI schedule of reinforcement. That is, a relatively high number of responses occurred in the presence of the training stimulus, and responding decreased as the difference between the value of the stimulus and the value of the training stimulus along the dimension of generalization increased. This result occurred when training was conducted with a VI 30-s, a VI 120-s, or a VI 240-s schedule, and when the dimension of generalization was wavelength or line orientation. When training was conducted with a VI 240-s schedule, more prolonged training tended to result in more responses being emitted during the generalization test and in slightly more extensive generalization (i.e., flatter gradients) for some subjects, although these effects were not statistically significant.

Frequency of Reinforcement

In keeping with the present findings, other research has shown that frequency of reinforcement in training may not be an important determinant of the extent of generalization in testing (e.g., Eckerman, 1969; Haber & Kalish, 1963). The data presented by Haber and Kalish (replotted in Figure 1-2) show that when key pecking by pigeons was maintained by a VI 15-s, a VI 60-s, or a VI240-s schedule of food presentation, gradients of generalization were similar. The only real difference was in the number of responses in the presence of the training stimulus. Subjects trained with the most frequent reinforcement (the VI 15-s group) responded more to the training stimulus than did the other subjects. Otherwise, the gradients were very similar. In addition, Eckerman (1969) showed that the extent of stimulus control following discrimination training (where stimulus control was defined as the ratio of responding in the presence of S+ to responding in the presence of S-) was equivalent for subjects trained with different probabilities of reinforcement in the presence of S+. Similar levels of stimulus control occurred for all subjects after approximately equal numbers of reinforcer deliveries, indicating that the absolute level of stimulus control did not depend on the frequency of reinforcement, as long as subjects had experienced some minimal number of reinforcers in training. Perhaps in the present Experiments I and II, the total number of reinforcers obtained during training was enough to establish equivalent levels of stimulus control following training with different VI schedules. That does not explain, however, why Hearst et al. (1964) found an effect of reinforcement schedule under conditions very similar to those employed in the present study.

Stimulus Dimension, Stimulus Disparity, and Stimulus Salience

It remains, therefore, to be explained why Hearst et al. (1964) observed flat generalization gradients along a line-orientation continuum following training with a VI 240-s schedule, whereas this result was not obtained in the present study. According to Dinsmoor (1995b), there are two stimulus parameters that influence the level of stimulus control that can be attained. These parameters are stimulus disparity and stimulus salience. Stimulus disparity refers to "the magnitude of the difference in physical units between [the stimuli to be discriminated]" (p. 254). Dinsmoor discusses this stimulus parameter by saying that the time required for a discrimination to form is a function of the physical difference between S+ and S-. This notion can also be applied to stimulus control as measured by the steepness of a generalization gradient. The amount of responding in the presence of a stimulus not present during single-stimulus training is, according to this idea, a function of the distance in physical units between the stimulus being tested and the stimulus used in training. It may be that the psychological difference between line orientations used in testing is less than the psychological difference between wavelengths in typical generalization experiments, and this may be why it seems more difficult to establish stimulus control by line orientation than by wavelength (cf., Baron, 1965; Born & Peterson, 1969; Carter & Eckerman, 1975; Davis, 1971; Harrison, 1991; Hearst, 1968; Hearst & Koresko, 1968; Honig et al., 1963; Lyons, 1969; Maki & Leuin, 1972; Marsh, 1972; Rilling, 1977). This analysis is not helpful in explaining the differences in extent of generalization observed in the present study as compared to those observed by Hearst et al. for subjects trained with a VI 240-s schedule. The spacing of stimuli along the line-tilt continuum was almost identical to that of Hearst et al., yet gradients were steep for all groups in the present study and there was much less responding in the presence of stimuli whose values lie at the ends of the continuum in the present study compared to the study by Hearst et al.

An account based on the second stimulus parameter described by Dinsmoor (1995b) may provide an explanation (although this explanation may not be more fruitful than that offered above). According to Dinsmoor, the extent of stimulus control is a function of the salience of the stimulus, or "the magnitude of the difference between the discriminative stimuli [i.e., the training stimulus] and the background stimulation" (p. 254). This relation may explain the difference in results obtained by Hearst et al. (1964) and those in the present Experiment II for subjects trained with a VI 240-s schedule. That is, line stimuli in the present study may have been more salient than lines in the study by Hearst et al. The discrepancy in results of other experiments that show gradients of generalization along a line-tilt continuum may be explained in a similar way.

In the present Experiment II one houselight was located above the center key on which the stimuli were projected in training and testing. In the study by Hearst et al. (1964) the houselight was located in the back of the chamber. The key was the same diameter (2.5 cm) in the present study as in the study by Hearst et al. The stimuli were white lines projected on the otherwise dark center key, just as in the study by Hearst et al., and were almost exactly the same width (0.4 cm in the present Experiment II and 5/16 inch in the study by Hearst et al.) In both studies the lines crossed almost the entire key. The main difference that may have resulted in differences in salience of the stimuli in the two studies is the location and/or brightness of the houselight. Hearst et al. did not report the brightness of their houselight; perhaps its brightness or location attenuated the salience of the lines. This account, however, requires that there be an interaction between stimulus salience and reinforcement frequency. Salience, presumably, was fixed in the study by Hearst et al., and they did observe decremental gradients for subjects trained with the shorter VI schedules.

Other researchers examining generalization along a line-orientation continuum have reported apparatus characteristics that differ with respect to the factors mentioned above (e.g., presence or absence, location, and brightness of houselights). No single factor stands out as a possible cause of the greater or lesser extent of stimulus control observed by different researchers. For example, Hearst and Koresko (1968) used a "dim" houselight and still observed a large amount of responding (approximately 50 to 150 responses) in the presence of line orientations whose values were far from the training stimulus on the line-tilt continuum. Schadler and Thomas (1972) obtained generalization gradients from pigeons trained to peck a key according to a VI 60-s schedule in the presence of a white line projected on a dark key in the absence of any houselight for ten 30-min sessions. This circumstance might be expected to increase the salience of a line projected on a key in an otherwise dark chamber; however, these authors observed approximately 200 to 320 responses to stimuli at the ends of the continuum over the course of 30 min of testing in the presence of the test stimuli (no blackouts intervened between presentations of different stimuli). Farthing and Hearst (1968) obtained a substantial level of stimulus control (i.e., most of the responses occurred in the presence of S+ and almost none occurred in the presence of S-), and they, too, had no houselight. Honig et al. (1963), whose stimuli consisted of black lines on a white background (rather than white lines on a black background, as in the studies just described) also had no houselight, and they observed more than 100 responses to line orientations at the ends of the continuum. Again, no single factor that may account for differences in salience appears to be responsible for the different levels of stimulus control established by researchers studying stimulus control by line orientation.

The explanation based on salience does not explain why flat gradients were not observed for all groups of subjects; subjects trained with the VI 30-s and VI 60-s schedules produced relatively steep gradients of generalization. It seems unlikely that the schedule of reinforcement interacts with salience of the stimuli to affect the shapes of generalization gradients. There is no reason to believe that line tilts that were not salient for subjects trained with a VI 240-s schedule would be salient for subjects trained with a VI 30-s or a VI 60-s schedule. Dinsmoor (1995b) offers another explanation for the level of stimulus control attainable, an interpretation based on attention.

Attention

According to Dinsmoor (1995b), stimulus control is established to the extent that the subject notices, or pays attention to, the relevant stimulus. Perhaps the subjects in the study by Hearst et al. (1964) that were trained with the VI 240-s schedule did not pay as much attention to (e.g., look at) the line present during training as did subjects trained with the shorter VI schedules. This account is similar to the explanation based on the relative control of responding by exteroceptive versus interoceptive or proprioceptive cues offered by Hearst et al. and Thomas and Switalski (1966). The latter hypothesis was used to explain different levels of generalization following two very different patterns of behavior established in training. Both sets of researchers claimed that the extent of stimulus control observed was a function of two very different patterns of behavior. Hearst et al. explained the lack of control by line orientation as resulting from a pattern of behavior that enhanced control by internal cues and attenuated control by external cues. A low rate of responding might be such a pattern, according to Hearst et al. Thomas and Switalski, on the other hand, explained their flat gradients obtained following VR training by saying that high rates result in control of responding by proprioceptive cues and decrease control by external cues. But, presumably, when pigeons are pecking a key, they are oriented toward the key. The higher the response rate, then, the more the pigeon sees (i.e., pays attention to) the key. Indeed, some researchers require a key peck before the relevant stimuli are presented in order to be sure the subject is oriented toward the key (Eckerman, 1969). High response rates should be correlated with high amounts of exposure to the key and the relevant stimulus and therefore with more stimulus control by the stimulus projected on the key. This correlation was not found in the present Experiment I; nor was it observed by Hearst et al.

It seems that a post hoc explanation of the extent of stimulus control based on the amount of attention paid to the stimulus is a weak one. According to Terrace (1966), attention is an empirical relation between a property of a stimulus and some measure of behavior. Just as the terms generalization and discrimination (which also refer to empirical relations) become a problem when they are used to explain the relations to which they refer, so does the term attention become a problem when it is used to explain the relation between stimuli and behavior to which it refers. Terrace states that the concept of attention arises "when a certain element of a stimulus that is correlated with reinforcement does not reliably control the response in question...The use of attention as an explanatory principle in these instances is begging the question, and seems to be nothing more than a mask for our ignorance concerning the establishment of stimulus control" (Terrace, 1966, p. 289).

One possible explanation of the lesser extent of stimulus control (i.e., the large number of responses to stimuli at the ends of the continuum and the flatter generalization gradients) observed by Hearst et al. (1964) for subjects trained with longer VI schedules is related to the concept of attention and can be tested empirically. Laboratories in the experimental analysis of behavior have used relays to control events during experimental sessions. Sometimes each experimental chamber had its own source of power; sometimes one power source was used to conduct sessions in different chambers at the same time. When the latter case held, a single timer often recorded seconds for all the chambers, and keylights flickered due to the pulse of the timer. This may have been the case in the study by Hearst et al., although they did not mention whether their chambers had independent sources of power. It is possible that key pecking came partly under the control of the flicker of the keylight, such that stimulus control by line orientation was diminished. Mackintosh (1965), describing the role of attention in "probability learning," in which different stimuli are correlated with different probabilities of reinforcement states that behavior can be controlled by "irrelevant" cues. "The presence of a strong irrelevant cue should serve to depress performance below the level attainable in its absence, since the irrelevant cue will compete with the relevant cue for control of behavior" (Mackintosh, 1965, p. 176). If keylights did flicker in the study by Hearst et al., this irrelevant cue may have attenuated control by the line on the key either by reducing the tendency to attend to the line or by preventing the correlation between the line and reinforcement from controlling subjects' behavior even though they did attend to the line. Perhaps control by irrelevant cues was greater for pigeons trained with the longer VI schedules in the study by Hearst et al. than for pigeons trained with shorter VI schedules because "an inconsistent [or less consistent] reinforcement schedule prevents [subjects] from learning consistently to attend to the relevant cue" (Mackintosh, 1965, p. 175). This hypothesis can be tested by the deliberate arrangement of irrelevant cues and the measurement of their effects on levels of stimulus control (Mackintosh, 1965).

Amount of Training

Dinsmoor (1995b) also cites evidence for his attentional interpretation of stimulus control from experiments that show that generalization gradients become steeper with more prolonged training. According to Dinsmoor, the greater degree of stimulus control is due to the increased amount of exposure to the stimulus. The present Experiment III, however, showed that when subjects were trained with a VI 240-s schedule of reinforcement in the presence of a 501-nm light for 32 to 57 sessions, they responded more during generalization testing and produced slightly flatter, rather than steeper, gradients than did subjects trained for ten sessions. Even though the statistical significance of this result is rather weak and depends, to a large extent, on the data of one subject (10575), results show that gradients of generalization did not get steeper as Dinsmoor would predict. These results are consistent with results from other experiments that show that more prolonged training (e.g., more than 20 sessions) results in flatter gradients of absolute generalization that are displaced upward relative to gradients obtained for subjects that experienced less training (Friedman & Guttman, 1963, as cited by Hearst & Koresko, 1968; Margolius, 1955; Mednick & Freedman, 1960; Olson & King, 1962). These results are in direct opposition to the general statement that generalization gradients become steeper as a function of amount of training (Dinsmoor, 1995a).

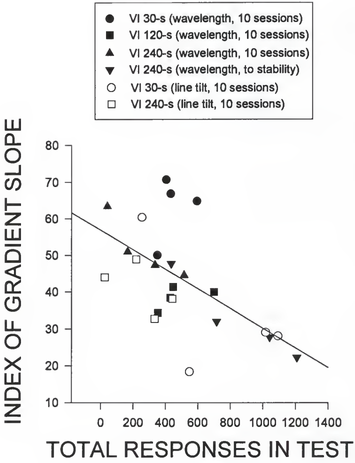
Index of Gradient Slope as a Function of Total Responses Emitted in Test

The extent of generalization, as indicated by the index of gradient slope, was not related systematically to response rates during training. However, index of gradient slope does appear to be related to the total number of responses emitted during the test. This relation is shown in Figure 5-1, which plots index of gradient slope as a function of total responses emitted during the test for all subjects in each experiment. Also shown is a regression line whose slope indicates that as the number of responses during the test increases, the proportion of responses emitted in the presence of the training stimulus (the index of gradient slope) decreases. The correlation coefficient (r) equals -.59, and this value is statistically significant ($p<.05$). This result suggests that conditions that result in more responses being emitted in the generalization test may also result in more extensive generalization. The data reported by Hearst, Koresko, and Poppen (1964) show that the subjects in their experiment emitted more responses during the test than did subjects in the present study, and the former also showed more extensive generalization than did the latter.

Latency as a Measure of Stimulus Control

The present set of experiments showed that latency to respond in the presence of a stimulus not present during training can be a valid indicator of the extent of stimulus control (see also Margolius, 1955; Rilling, 1977). When

Figure 5-1. Indexes of gradient slope plotted as a function of total responses emitted in the generalization test for all subjects in all three experiments. Also shown is a regression line fitted to the data.


● VI 30-s (wavelength, 10 sessions)
■ VI 120-s (wavelength, 10 sessions)
▲ VI 240-s (wavelength, 10 sessions)
▼ VI 240-s (wavelength, to stability)
○ VI 30-s (line tilt, 10 sessions)
□ VI 240-s (line tilt, 10 sessions)
INDEX OF GRADIENT SLOPE
80
70
60
50
40
30
20
10
0
200
400
600
800
1000
1200
1400
TOTAL RESPONSES IN TEST

latencies to respond in the presence of a stimulus were plotted as a function of the distance between the value of the stimulus and the value of the training stimulus along the dimension of generalization, orderly gradients of generalization were constructed. The characterization of generalization by these gradients was similar to the characterization that resulted when absolute and relative generalization were analyzed, a result that indicates that latency to respond may be a valid measure of the extent of stimulus control. Latency from the first block of testing may be sufficient to analyze the extent of generalization to stimuli not present during training. Therefore, latency measures for one presentation of each test stimulus may be all that is needed to obtain reasonably accurate characterizations of stimulus control.

Gradient Changes in Extinction

A final result of the present set of experiments concerns the shape of generalization gradients across the course of testing in extinction. In general, responding decreased across the test session, and absolute generalization gradients often were displaced downward for the later blocks of the session relative to earlier blocks (see also Friedman & Guttman, 1965; Guttman & Kalish, 1956; Hiss & Thomas, 1963; Honig et al., 1963; Kalish & Haber, 1963; Rilling, 1977). Relative generalization gradients typically did not change much over the course of extinction (see also Guttman & Kalish, 1956; Hiss & Thomas, 1963; Honig et al., 1963), or they became steeper across blocks of the test session (see also Friedman & Guttman, 1965; Jenkins & Harrison, 1960; Kalish & Haber, 1963; Thomas &

Barker, 1964). This latter result is consistent with data that show that the stimuli at the ends of the continua may lose their effectiveness more rapidly than do stimuli whose values lie closer to the value of the training stimulus on the dimension of generalization (Friedman & Guttman, 1965). In the present study, however, this effect was not robust, a result that indicates that, perhaps, total responding decreases across the course of testing in extinction equally for different stimulus values.

Conclusion

In summary, the present set of experiments examined the reliability of the relation between frequency of reinforcement and extent of generalization reported by Hearst et al. (1964) and found the effect to be less than robust. These results indicate that this phenomenon may not be useful as a basis for developing treatments that result in differing amounts of stimulus generalization. In the present study when the same procedure was used to test for stimulus control, it was possible to obtain generalization gradients of similar shape along different dimensions of generalization (i.e., wavelength and line orientation) using VI schedules that varied in terms of the VI mean interval. Finally, it was found that generalization gradients can become flatter with prolonged VI training. This last result suggests that when extensive generalization is desirable, prolonged training may be an effective strategy for training adaptive behavior.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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